Jennifer Yeo · Tang Wee Teo
Kok-Sing Tang *Editors*

Science Education Research and Practice in Asia-Pacific and Beyond

Springer

Science Education Research and Practice in Asia-Pacific and Beyond

Jennifer Yeo • Tang Wee Teo • Kok-Sing Tang
Editors

Science Education Research and Practice in Asia-Pacific and Beyond

Springer

Editors
Jennifer Yeo
National Institute of Education
Nanyang Technological University
Singapore

Tang Wee Teo
National Institute of Education
Nanyang Technological University
Singapore

Kok-Sing Tang
Curtin University
Perth, Australia

ISBN 978-981-10-5148-7 ISBN 978-981-10-5149-4 (eBook)
DOI 10.1007/978-981-10-5149-4

Library of Congress Control Number: 2017947727

© Springer Nature Singapore Pte Ltd. 2018
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

This book is motivated by the research presentations at the International Science Education Conference (ISEC) 2014. Centred on the theme of ‘Pushing the boundaries – Investing in our future’, these papers sought to pursue new ways of helping learners of science appreciate the diversity and changes in science that result from a globalised world facing complex and diverse environmental and technological issues. This book thus aims to showcase some of the best papers presented in ISEC 2014.

The conference attracted many presentations of research conducted by researchers not only in Singapore but also in the Asia-Pacific region and beyond. Also noteworthy were the presentations by Singapore science teachers whose research were aimed at advancing their pedagogical practices in order to improve students’ learning and to prepare them for the present and future challenges. In this book, we showcase some of the finest papers presented by researchers from the Asia-Pacific region and beyond, as well as those conducted by science teachers. These chapters touch on various themes in science education that explore and investigate issues of scientific literacy, societal challenges and affect and teacher professional development. As we forge forward to address the challenges facing science educators in our own contexts, we hope these chapters will engender new ideas and conversation among science educators.

This book is divided into three parts. Part I focuses on different aspects of scientific practices, Part II examines societal issues and affective dimensions of science learning, and Part III explores different teacher education models for preparing science teachers to face the complex pedagogical challenges of today’s classroom.

Part I consists of chapters surrounding scientific practices. It opens with a chapter by Erduran, Kaya and Dagher on conceptualising scientific practices as components of the nature of science. In this chapter, the authors argued for the inclusion of scientific practices for a more holistic consideration of the nature of science, based on the notion of the family resemblance approach. Further, they reported findings how the model was used to inform pre-service teacher education programmes in Turkey and influenced pre-service teachers’ representations of scientific practices. Chapters 2, 3, 4 and 5 examine the different aspects of scientific practices – modelling, scientific explanations, report writing and use of evidence. In Chap. 2, Gilbert and Justi reviewed and critiqued research and practices of modelling, one of the key aspects of scientific practices, in East Asia. They also presented a model of modelling to support teachers in implementing modelling-based teaching in the classroom. In Chap. 3, Talanquer foregrounded the challenges students face when producing mechanistic explanations in chemistry. His finding about the unproductive use of intuitive schemas constructing mechanistic explanations in chemistry highlights the need for more productive ways of thinking rather than acquisition of fragmented knowledge in chemistry education. In Chap. 4, Putra and Tang's focus was on the scientific practice on communication, particularly in report writing. They put forth a case for the need to help students unpack the characteristics of scientific report. Their finding, showing the lack of authoritativeness and rhetoric in students' scientific report, highlights the need to help students unpack the characteristics of scientific report as well as on writing in science learning. In Chap. 5, Oshima and Roberts examined another aspect of scientific practices, that is, students' understanding of evidence. As an exploratory study of Japanese students' understanding of evidence, the authors found that students seemed to conceptualise the idea from a 'doing' perspective even though they appeared to have a good grasp of variables in the context of scientific investigations. They concluded the chapter with calls for understanding evidence as a set of concepts and variables rather than process skills to be mastered by doing.

Part II is a collection of papers that highlights societal issues and affective dimension of learning. In Chap. 6, Dillon highlighted the need for convergence in science education and environmental education if we were to educate the next generation of some of the pressing environmental and biodiversity issues that are facing the society. In Chap. 7, Alsop reminded us that science learning was not all about achievement scores. Rather, the role of interest is an important part of science learning and should not be ignored. And indeed, Chaps. 8 and 9 showed us how play can engage students' interest and bring about science learning among preschoolers. In Chap. 8, DeSouza explored how young children learn science-related concepts when interacting with nature in an outdoor classroom, and the extent the 5E instructional model aided preservice teachers in their planning and use of inquiry-based practices to design the learning process. In Chap. 9, Teo, Yan, Ong and Goh demonstrated how purposeful play could contribute to young children's science experiential learning and understanding as they participated in science activities at a garden. The affordances of purposeful play, as illuminated through the teacher-students and student-student social interaction, gave us a glimpse on how to capitalise on naturalistic context to enhance children's learning.

The chapters in Part III joined the conversation of preceding chapters by focusing on issues surrounding professional development and classroom implementation. In Chap. 10, Tan and Gilbert examined the impact of educational research in informing Singapore middle and high school chemistry teachers' instructional and curricular practices and presented factors which facilitated or impeded changes in Singapore teachers' existing practices. In Chap. 11, Yeo surveyed the presentations made by teacher researchers during ISEC 2014 and showcased some of these research as well as identified the extent that teacher research supported professional development of in-service teachers. In Chap. 12, Ramnarain examined the extent that physical sciences teachers at township schools in South Africa constructed a coherent ‘science content storyline’ in teaching chemistry. Conducted as part of a video-based analysis-of-practice professional development programme to improve teacher and student learning at the upper elementary level, findings showed that the lessons were fragmented, disconnected and incoherent. His inference of the low achievement of chemistry in the country to conceptual incoherence in the classroom foregrounded the importance of these pedagogical characteristics in teachers’ professional development in ensuring students’ conceptual development in science. In Chap. 13, Namsone and Čakāne introduced a teachers’ continuous professional learning model which emphasised on teacher collaboration to enhance teachers’ professional development. Their investigation showed that the model had enhanced the development of teaching, reflection and collaboration skills among the mathematics and science teachers, as well as primary school teachers, who participated in the study. We concluded the section with Chap. 14 by Chan and Yung, who illustrated the importance of subject matter analysis and formative assessment of students when experienced science teachers need to teach new content. Consequently, they proposed a three-step mechanism of on-site development process that could support science teachers in developing the requisite knowledge for teaching new topics that they had never taught before.

In sum, we hope that these papers provide a platform for evoking new research ideas and discussions for the science education research fraternity and inspire new conversations at the next ISEC.

Singapore Jennifer Yeo
Singapore Tang Wee Teo
Australia Kok-Sing Tang

Contents

Part I Practices of Science

Part II Societal and Affective Dimensions of Science

Part III Teacher Professional Development

About the Authors

Steve Alsop is a professor in the Faculty of Education and Department of Science and Technology Studies at York University, Toronto, Canada. He teaches courses in science and technology education, environmental sustainability education, climate change education and STS. Steve's areas of research interests explore the personal, social and political organisation of scientific and technological knowledge in educational and environmental contexts and settings. He has a lasting interest in affect, which he sees as central to education and science but often underrepresented in research and policy. He has published widely; his latest book is a coedited volume exploring activism in science and technology (Springer Press). His latest research project is exploring a 50-year cultural history of the Ontario Science Centre. (salsop@edu.yorku.ca)

Līga Čakāne is a researcher at the Interdisciplinary Center for Educational Innovation, University of Latvia. She has worked as a teacher, school management representative and expert in curriculum development. Currently she is leading teachers' continuous professional development workshops. Her research interests are curricula development according to deep (competency-based) learning and teacher competence development models. (liga.cakane@lu.lv)

Kennedy Kam Ho Chan is an assistant professor at the University of Hong Kong (HKU). He received his B.Sc. and M.Phil. degrees in science from HKU. Before pursuing his Ph.D. studies at the same university, he worked as a secondary school science teacher in local secondary schools. His research interests include pedagogical content knowledge (PCK), teacher noticing, using videos to promote teacher learning and formative assessment. He is a recipient of various scholarships and awards including Hong Kong Ph.D. Fellowship, Sir Edward Youde Memorial Fellowship (For Postgraduate Research Students) and International Science Education Conference (ISEC)-Springer Best Paper Award (Student Category). He was an invited participant of PCK Summit II held in the Netherlands. (kennedyckh@hku.hk)

Zoubeida R. Dagher is a professor of science education at the School of Education and a faculty fellow at the Center for Science, Ethics, and Public Policy, University of Delaware. She currently serves as president of the International History and Philosophy of Science Teaching (IHPST) Group. Her recently co-authored book with Professor Erduran, titled *Reconceptualizing the Nature of Science for Science Education: Scientific Knowledge, Practices and Other Family Categories* (Springer, 2014), proposes a detailed holistic and comprehensive account for embedding scientific epistemology in science curriculum and instruction. (zoubeida@udel.edu)

Josephine M. Shireen DeSouza is an associate professor of biology at Ball State University in the USA. She has a Ph.D. in curriculum and instruction from the University of Toledo, Ohio; a B.Sc. in chemistry and an M.Ed. in secondary science education from the University of Madras, India; and a B.Ed. and an M.A. in English literature from the University of Mysore, India. Her research has focused on teachers' science teaching efficacy beliefs and qualitative studies on science learning behaviours of young children. (jmshireen.desouza@gmail.com)

Justin Dillon is professor of science and environmental education at the University of Bristol where he has worked since 2014. Prior to this appointment, he was head of the Science and Technology Education Group at King's College London. After studying for a degree in chemistry, Justin trained as a teacher and taught in inner London schools from 1980 until 1989 when he joined King's. Justin is a co-editor of the *International Journal of Science Education* and was president of the European Science Education Research Association from 2007 to 2011. (justin.dillon@bristol.ac.uk)

Sibel Erduran is a professor of science education at the University of Oxford, UK. She also holds a distinguished chair professor position at National Taiwan Normal University in Taiwan. She is an editor for the *International Journal of Science Education* and section editor for *Science Education* and serves on the Executive Board of the European Science Education Research Association. Previously she held positions in Ireland, Turkey, Sweden as well as the UK. Her research interests focus on the applications in science education of epistemic perspectives in science in general and in chemistry in particular. (Sibel.Erduran@education.ox.ac.uk)

John K. Gilbert took a B.Sc. in chemistry at the University of Leicester (1962), a D.Phil. in chemistry at the University of Sussex (1965) and a PGCE (Secondary Science) at the University of London (1968). He taught at King's School Rochester and at Banbury School until 1971 when he took up a lectureship in science education at the University of Keele, moving to the University of Surrey as a senior lecturer in 1974, subsequently becoming a reader in 1984. In 1988 he become professor of science education at the University of Reading, becoming professor emeritus in 2005. He is co-chief editor of the *International Journal of Science Education* (A) and (B). His initial research interests in children's 'alternative conceptions' evolved into a focus of 'models and modelling' and most recently to both 'visualisation and explanation' and to 'science communication'. In 2001 he received the NARST award for 'Distinguished Contributions to Science Education Through Research'. (john.k.gilbert@btinternet.com)

Mei Ting Goh was a research assistant at the National Institute of Education, Nanyang Technological University, Singapore.

Rosária Justi is full professor of science education at the Universidade Federal de Minas Gerais in Brazil. She holds a bachelor's degree in chemistry, a master's degree in education and a Ph.D. in science education. She taught chemistry in secondary schools in Brazil for some years before moving into teachers' education and science education research. She has been an associate editor of the *International Journal of Science Education* and the editor-in-chief of the *Brazilian Journal of Research in Science Education*. Her current main research interests are modelling-based teaching, argumentation in science education and the introduction of history and philosophy of science in science education. (rosariajusti@gmail.com)

Ebru Kaya is an associate professor in science education at Bogazici University, Turkey. Dr. Kaya's research interests include argumentation and nature of science in science education. Dr. Kaya has participated in research projects funded by TUBITAK (Turkish Scientific and Technological Research Council) and NARST and conducted professional development workshops for science teachers in Turkey, Rwanda and Lebanon. She has authored close to 70 publications including papers in journals and proceedings. She served as a member in the NARST Outstanding Paper Award Committee from 2013 to 2015. (ebru.kaya@boun.edu.tr)

Dace Namsone is a director at the Interdisciplinary Center for Educational Innovation, University of Latvia. She holds an M.Sc. in education and a Ph.D. in chemistry from the University of Latvia. As a leading researcher, she conducts research on teachers' professional development, competency-based education and teacher collaboration directly linked to teaching science and mathematics. Her past and current work is related to implementing innovations to improve teaching and learning of science and mathematics subjects. She has experience in leading teacher workshops related to continuous professional development. (dace.namsone@lu.lv)

Woei Ling Monica Ong is a teaching fellow at the Centre for Research in Pedagogies and Practice, National Institute of Education, Nanyang Technological University, Singapore. She has 11 years of experience teaching secondary school students history and geography and was a department head. Her research interests include teacher learning and learning communities. (monica.ong@nie.edu.sg)

Ryugo Oshima is assistant professor at the Faculty of Education, Chiba University, Japan. His research interests include how students think the validity and the reliability of data in an investigation and how teachers can help students examine data.

He is also involved in teacher training programmes for other countries at the university. (ryugo.oshima@chiba-u.jp)

Gde Buana Sandila Putra is a graduate student at the National Institute of Education, Nanyang Technological University, Singapore. He has been involved in several research projects examining and developing disciplinary literacy teaching and learning in elementary and secondary schools. Prior to his research involvement, he taught experiment-based science enrichment classes in elementary schools. His current research interests are in the area of disciplinary literacy in the sciences. (gde.putra@nie.edu.sg; http://www.nie.edu.sg/profile/putra-gde-buana-sandila)

Umesh Ramnarain is a professor in science education at the University of Johannesburg, South Africa. His main research interest is on inquiry-based science education, with a particular focus on its uptake in South African classrooms, where the unequal funding policies of the previous apartheid education system have resulted in learning contexts that are complex and diverse. His work has been published in high-impact-factor journals such as the *International Journal of Science Education*, *Research in Education* and the *Journal of Research in Science Teaching*. (uramnarain@uj.ac.za)

Ros Roberts is a senior lecturer in science education in the School of Education, Durham University, UK, having previously taught in comprehensive schools and further education. She now teaches undergraduate and postgraduate initial teacher education students about scientific evidence. Her research interests include how scientific practice is specified in the science curriculum, teaching and assessment of scientific evidence, the role of practical work and fieldwork and scientific literacy in both school and university curricula. (rosalyn.roberts@durham.ac.uk; https://www.dur.ac.uk/education/staff/profile/?id=635)

Vicente Talanquer is a distinguished university professor in the Department of Chemistry and Biochemistry at the University of Arizona. His research focuses on the characterisation of students' reasoning about chemical entities and phenomena and how these ways of thinking evolve with training in the discipline. He uses the results of his studies to design educational resources to support chemistry teaching and learning. (vicente@u.arizona.edu; http://cbc.arizona.edu/faculty/vicente-talanquer)

Kim Chwee Daniel Tan started his career as a chemistry teacher in 1990. He has been a faculty member of the National Institute of Education, Nanyang Technological University, Singapore, since 1998. He is the co-editor of *Pedagogies: An International Journal* and is currently on the editorial boards of the *International Journal of Science Education* and *Chemistry Education Research and Practice*. His research interests are chemistry curriculum, translational research, ICT in science education, students' understanding and alternative conceptions of science, multiple representations and practical work. (daniel.tan@nie.edu.sg; http://www.nie.edu.sg/profile/tan-kim-chwee-daniel)

Kok-Sing Tang is a senior lecturer at the Science and Mathematics Education Center (SMEC), School of Education at Curtin University. He was formerly an assistant professor at the National Institute of Education, Nanyang Technological University, Singapore. He holds a B.A. and M.Sc. in physics from the University of Cambridge and an M.A. and Ph.D. in education from the University of Michigan. His current research examines the disciplinary literacy of science, which comprises the specific ways of talking, writing, representing and doing that are required in scientific knowledge construction. (kok-sing.tang@curtin.edu.au; http://curtin.edu.au/staff/profile/view/kok-sing.tang)

Tang Wee Teo is an assistant professor at the National Institute of Education, Nanyang Technological University, Singapore. She applies a critical lens to examine diverse equity issues in science education that affect learners (e.g. lower-track students, children aged 6–8 and international students) who are underrepresented in the local and international literature. Her current work focuses on lower-track science students' science learning experiences. As a trained chemist and chemistry education professor, she also actively publishes in chemistry education journals. (tangwee.teo@nie.edu.sg; http://www.nie.edu.sg/profile/teo-tang-wee)

Yaw Kai Yan is an associate professor at the National Institute of Education, Nanyang Technological University, Singapore. He has been involved in the training and professional development of science teachers (grades 3–12) for over 20 years. While Yaw Kai's Ph.D. training is in chemistry, he undertakes research in both the content and pedagogical aspects of the subject and publishes in both chemistry and education journals. (yawkai.yan@nie.edu.sg; http://www.nie.edu.sg/profile/yan-yaw-kai)

Jennifer Yeo is an assistant professor at the National Institute of Education, Nanyang Technological University, Singapore. She taught physics at the secondary level for 8 years in Singapore schools. Her research interests include understanding how students produce explanation in science and the role of representations in mediating thinking and reasoning. She also works actively with school teachers in their action research. (jennifer.yeo@nie.edu.sg; http://www.nie.edu.sg/profile/yeo-jennifer)

Benny Hin Wai Yung was associate professor and head of the Science, Mathematics and Computer Education Division in the Faculty of Education at the University of Hong Kong before his retirement in 2015. His research interests included using video for teacher education, teacher professional development, teacher thinking and teacher belief, assessment in education including school-based assessment, alternative assessment and international comparative studies in students' science achievement. (hwyung@hku.hk)

Part I
Practices of Science

Chapter 1
From Lists in Pieces to Coherent Wholes: Nature of Science, Scientific Practices, and Science Teacher Education

Sibel Erduran, Ebru Kaya, and Zoubeida R. Dagher

Abstract The chapter provides a case for holistic consideration of nature of science (NOS) such that NOS can be inclusive of themes as scientific practices. One account of NOS is based on the family resemblance approach (FRA) developed by Erduran and Dagher (Reconceptualizing the nature of science for science education: scientific knowledge, practices and other family categories. Springer, Dordrecht, 2014a). In this framework, NOS is a cognitive-epistemic and social-institutional system, and scientific practices is one category embedded in the system. We briefly review the recent debates on NOS to contextualize our approach and define FRA-based NOS. As part of our depiction of scientific practices as a component of NOS, we proposed a theoretical framework called the benzene ring heuristic (BRH) which consolidates the epistemic, cognitive, and social aspects of scientific practices into a holistic and visual representation. BRH describes scientific practices in terms of concepts such as data, models, explanations, predictions, argumentation, and social certification. After reviewing BRH, we describe a funded project that integrated BRH in a preservice science teacher education program in Turkey. Qualitative analysis of preservice science teachers' representations of scientific practices is described in detail and contrasted pre- and post-intervention that involved training through the use of BRH. The results indicate that in some cases there was improvement in preservice science teachers' depiction of scientific practices as being holistic. The study provides empirical evidence on the implementation of a relatively new approach to NOS that is inclusive of scientific practices.

S. Erduran (✉)
University of Oxford, Oxford, UK

National Taiwan Normal University, Taipei City, Taiwan
e-mail: Sibel.Erduran@education.ox.ac.uk

E. Kaya
Bogazici University, Istanbul, Turkey

Z.R. Dagher
University of Delaware, Newark, DE, USA

J. Yeo et al. (eds.), *Science Education Research and Practice in Asia-Pacific and Beyond*, DOI 10.1007/978-981-10-5149-4_1

Introduction

The nature of science (NOS) has been a predominant area of research in science education (Allchin 2011; Alters 1997; Erduran 2017; Erduran and Dagher 2014a; Irzik and Nola 2014; Lederman 1992; McComas et al. 1998). NOS has also infiltrated curriculum policy documents worldwide including key documents such as Science for all Americans (AAAS 1989) and Science Education Content Standards (NRC 1996) in the USA and Specifications for Junior Cycle Science in Ireland (NCCA 2015). A comparative study of eight curriculum standards that included four from the USA and four from Australia, Canada, England/Wales, and New Zealand illustrates the level of interest in NOS (McComas and Olson 1998).

In a review of the literature between 1990 and 2007, Chang et al.' (2010) identified an approach to NOS labeled as the "consensus view" of the nature of science (Abd-El-Khalick 2012; Lederman et al. 2002). This view supports emphasis on seven key aspects or tenets deemed appropriate for school science that include (1) tentativeness of scientific knowledge, (2) observations and inferences, (3) subjectivity and objectivity in science, (4) creativity and rationality, (5) social and cultural embeddedness in science, (6) scientific theories and laws, and (7) scientific methods. The "consensus view" has led to a major body of empirical studies on student and teacher conceptions of NOS in science education (Abd-El-Khalick and Lederman 2000) and has culminated in several points of debate in the science education community. One of the issues in this debate pertains to Lederman's (2007) stance that even though NOS and scientific inquiry are related, they should be differentiated. The main premise of this argument is that "inquiry" can be specified as the methods and procedures of science, while the NOS concerns more on the epistemological features of scientific processes and knowledge. Grandy and Duschl (2008) have disputed these arguments on the basis that they "greatly oversimplify the nature of observation and theory and almost entirely ignore the role of models in the conceptual structure of science" (p. 144). Erduran and Dagher (2014a) proposed a more holistic account of NOS by drawing on the family resemblance approach where scientific methods, practices, and other aspects such as the social-institutional dimensions all contribute to a definition of NOS.

Additional critiques focus on the declarative statement characteristic of the consensus view, which may constrain thought about NOS. Allchin (2011) calls for "reframing current NOS characterizations from selective lists of tenets to the multiple dimensions shaping reliability in scientific practice, from the experimental to the social, namely to Whole Science" (p. 518). He argues that many items related to science as an enterprise, for instance, the role of funding, motivations, peer review, cognitive biases, fraud, and the validation of new methods, are absent in the "consensus view" of NOS list, and yet they are "unified by the theme of reliability." From Allchin's perspective, this shift better prepares students for dealing with how claims might fail and how scientists deal with sources of error (Allchin 2011, p. 524). Allchin states that:

> *Whole Science, like whole food, does not exclude essential ingredients. It supports healthier understanding. Metaphorically, educators must discourage a diet of highly processed, refined "school science." Short lists of NOS features should be recognized as inherently incomplete and insufficient for functional scientific literacy*. (Allchin 2011, p. 524)

Noting the limitations of the consensus view, Matthews (2012) suggests replacing the notion of "nature" of science (NOS) with "features" of science (FOS) that encompass a more inclusive range of ideas about science that would be possible by strictly following an epistemological emphasis, or focusing on scientific knowledge, as is the case with the "consensus view." The FOS features that Matthews has proposed resemble a disparate set of ideas some of which reflect epistemic aspects of science on the one hand (e.g., explanation, theory choice, and rationality), while others reflect a philosophical stance (e.g., feminism, realism, and constructivism).

The brief introduction to some recent debates on NOS illustrates that while questions on what NOS content is optimal for school science have been settled for proponents of the consensus view, they are far from settled for others. In our work, we have previously argued that one of the limitations of the consensus accounts of NOS is that the declarative statements do not necessarily promote a holistic account of NOS where the various features of NOS are interrelated (Erduran and Dagher 2014a). When various aspects of NOS remain fragmented as lists of ideas, there is danger of not promoting understanding of science a coherent whole. There is already ample evidence that many students are turned off of science because they do not see the relevance of science for their everyday lives, and significant amount of work has been done in related areas of research to socially contextualize science for effective learning (e.g., Zeidler et al. 2002).

In this chapter, we present an argument for a broad articulation of NOS to include scientific practices. Our account draws on recent theoretical work drawing on the family resemblance approach (FRA) to NOS (Erduran and Dagher 2014a) referred to by Kaya and Erduran (2016) as "RFN" (short for "Reconceptualised Family Resemblance Approach to NOS"). Given FRA-based NOS accounts are relatively new and limited in the science education literature (e.g., Irzik and Nola 2014), our aim is to contribute to this discussion by also providing some empirical evidence on the utility of this approach to NOS. After reviewing the theoretical framework on NOS and scientific practices, we illustrate the application of a heuristic on scientific practices in preservice science teacher education. The heuristic is derived from a theoretical account of scientific practices as subsumed within NOS (Dagher and Erduran 2016; Erduran and Dagher 2014a) and has been applied to the design of a teacher training intervention program. We illustrate how the heuristic has been used in teacher training and the impact of the intervention on preservice science teachers' representations of scientific practices.

Nature of Science Based on the Family Resemblance Approach

The family resemblance approach (FRA) to NOS points to a wide range of shared and distinctive scientific practices, methodologies, aims and values, social norms, and the very aspects that contextualize and frame scientific knowledge (Erduran 2014; Erduran and Dagher 2014a; Irzik and Nola 2014; Kaya and Erduran 2016). We have previously argued that excluding any of these is to deny access to key aspects of these disciplinary elements and consequently results in limited attention to factors that influence the formation and validation of scientific claims (Dagher and Erduran 2016). The advantage of using the FRA to characterize a scientific field of study is that it allows a set of broad categories to address a diverse set of features that are common to all the sciences and the activities carried out within them. This is particularly useful in science, where all subdisciplines share a number of common characteristics, but no one specific characteristic per se can be used to define a domain as scientific or to demarcate it from other disciplines. For instance, if we take observation (i.e., human or artificial through the use of detecting devices) and argue that even though observing is common to all the sciences, the very act of observing is not exclusive to science and therefore does not necessarily grant family membership in and of itself. The same applies to other practices such as making inferences and collecting data, whereby these are shared by the sciences, but their use is not necessarily limited to science disciplines. One of the appealing aspects of the FRA is its ability to consolidate the epistemic, cognitive, and social aspects of science in a wholesome, flexible, descriptive but non-prescriptive way. FRA provides focus zones that support the discussion of critical elements about science that can potentially be fruitful for science educators as well as among teachers and students.

The FRA captures a meta-level characterization of the key categories related to science in a broad sense. In other words, the FRA is more inclusive of various aspects in its depiction of science. It is the holistic, inclusive, diverse and comprehensive, and meta-level conceptualization of FRA that we have argued to be appealing for science educators (Dagher and Erduran 2016). Having a more diverse representation of science has potentially more appeal to wider range of students. For example, students who may not necessarily be drawn to the epistemic dimensions of science may now find more motivation and interest in the social-institutional aspects of science.

How do the components of science as a cognitive-epistemic system relate to those of science as a social-institutional system? This relationship is considered in terms of the FRA Wheel presented in Fig. 1.1 from Erduran and Dagher (2014a). The idea can be characterized in the following way. Science as a cognitive-epistemic system occupies a space divided into four quadrants that accommodate its four categories. This circle floats within a larger concentric one also divided into four quadrants, pertaining to the four components of science as a social-institutional system. This, in turn, is surrounded by an outermost circle that includes the three additional components. Locating the three new categories in the outer circle simply indicates

Fig. 1.1 Family resemblance approach (FRA) wheel from Erduran and Dagher (2014a, p.28)

the role of societal influences on the scientific enterprise further reinforcing that science is not insulated from the larger society in which it exists. The boundaries between the circles (or spaces) and the individual compartments of the FRA Wheel are porous, allowing fluid movement among its components. In reality, these components are not compartmentalized but flow naturally in all directions. One of the FRA categories concerns scientific practices which have been gaining increasing attention since the publication of the *Next Generation Science Standards* in the USA (NGSS Lead States 2013). In the subsequent sections, we turn to a discussion of scientific practices and explore the implications of our conceptualization of scientific practices in science teacher education.

Scientific Practices as a Component of Nature of Science

The National Research Council (NRC 2012) of National Academy of Sciences designed a framework for K-12 science education in order to create standards of science education. The framework is based on evidence-based findings of current research and introduced three major dimensions of science education. Scientific practices were recommended as one of them and defined as “(a) the major practices that scientists employ as they investigate and build models and theories about the world” (NRC 2012, p.30). The National Research Council (NRC 2012) presented eight practices that propose the necessary components of science curriculum. These are:

1. Asking questions (for science) and defining problems (for engineering)

2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information (p. 49)

Research revealed that including these practices in the science curriculum helps students understand scientific knowledge development, the way scientists work, and may increase students' cognitive abilities (NRC 2012). On the other hand, curriculum by itself may not be enough for understanding and experiencing scientific practices. Teachers as the major actors of learning environment should also have an understanding of scientific practices per se.

Zembal-Saul (2009) emphasizes children's engagement in appropriate scientific practices, discourses, and reasoning. It was suggested that a standard-based curriculum should be provided for teachers to support students engaging in scientific practices (NRC 2012). Erduran and Dagher (2014a) discuss that scientific practices and science process skills need to be differentiated. Scientific practice is a term that engages skills and knowledge meaningfully to make scientific investigation. In this respect, it is more comprehensive than the term science process skills. In other words, scientific practices do not only involve practicing skills but also refer to making sense of the relationship between skills and underlying scientific content knowledge and epistemology. In order to appreciate the nature of scientific knowledge, one has to both understand and experience scientific practices. Hence, scientific practices were also emphasized in nature of science studies (Irzik and Nola 2014; Erduran and Dagher 2014a, b). This recent line of nature of studies focuses on the importance of scientific practices for appreciation of science. In this respect, it substantially contributes to previous nature of science studies which suggest explicitly teaching the aspects of nature of science (Abd-El-Khalick and Lederman 2000).

In our previous work, we have developed a framework of scientific practices, namely, benzene ring heuristics (BRH) (Erduran and Dagher 2014a). BRH includes epistemic, cognitive, and social components. Epistemic components refer to scientific activities, data, real world, model, explanation, and prediction. These components also refer to the features of the scientific practices. Cognitive and social components, respectively, refer to representations and reasoning and social dissemination and certification of scientific claims. BRH suggests that all features of scientific practices are related to each other and these relationships do not have a linear order. In other words, holistic understanding of scientific practices was emphasized with the representation referring to an analogy that is benzene ring. In this heuristic, components of scientific practices represent the atoms, and the social components (representation, reasoning, discourse, social certification) stand in the place of electron clouds (See Fig. 1.2). The representation in Fig. 1.2 is inclusive of the components of science, the nonlinear relationships between these components, and a holistic understanding of science. Therefore, BRH makes a strong contribution

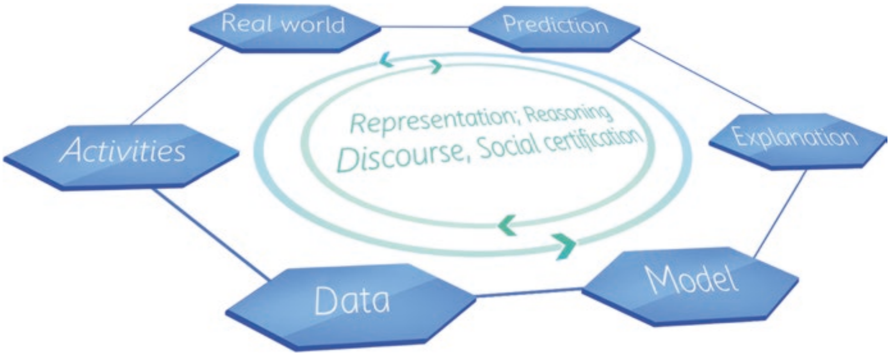


Fig. 1.2 Benzene ring heuristic (BRH) (Erduran and Dagher 2014a, b, p.82)

overcoming the procedural understanding of science with its holistic approach. Given BRH is a theoretical framework by nature, we wanted to explore the implications of its implementation in practice. Here we will review its adaptation to science teacher education and describe a research project based in Turkey where we integrated BRH to teacher training and investigated the impact on preservice science teachers.

Methodology

The study reported in the following section focused on introducing BRH as a heuristic of scientific practices to develop preservice teachers' understanding of scientific practices. In other words, this study aimed to investigate preservice science teachers' representations of scientific practices in terms of features and the relationships between these features of scientific practices, as well as the holistic understanding of scientific practices. Moreover, the study investigated the influence of a teacher training intervention workshops. The research was guided by the following question: *What are the preservice science teachers' representations of scientific practices before and after a set of training workshops informed by the BRH?* The full description of the intervention is available as a teacher training resource (Erduran et al. 2016).

Sample

The sample of the study comprised 21 preservice science teachers: 18 females and 3 males. All participants were third-year students in a 4-year science teacher education program of a state university in Turkey. The language of instruction at this university is English. Upon graduation, the preservice teachers in this study would be qualified to teach science in primary schools (Grades 3–8).

Research Design

In order to develop students' representations of scientific practices, an intervention consisting of three structured workshops on scientific practices based on BRH was carried out. Each workshop was taught for 3 hours. The workshops aimed to consolidate preservice teachers' understanding of the BRH by (a) reviewing its application to particular science examples and (b) using BRH for lesson planning. In Table 1.1 the aims and content of the workshops are summarized. In the first workshop, an example activity on "acids and bases" (Appendix) was used to illustrate the various components of BRH. The preservice teachers used everyday acids and bases (real world) to collect sensory data (data) in order to generate a model (model) of the key properties of acids and bases. They subsequently used their models to explain and predict (explanation, prediction) what would happen at neutralization. In other words, the activity explicitly promoted the articulation of the BRH and its components. There were group discussions and evaluations of the models produced, which promoted argumentation, reasoning, and social certification of ideas. These were considered to be the mediational components of the BRH represented by the internal electron cloud analogy in Fig. 1.2.

Both quantitative and qualitative data were collected before and after the training in order to investigate various aspects of preservice science teachers' perceptions and understanding of scientific practices. In this chapter, we are focusing on the qualitative data and in particular the comparison of representations of scientific practices. The representations were from posters that five groups constructed before and after the sequence of workshops. Each poster is described in depth, comparing and contrasting their features. Each poster resulted in a particular representation of scientific practices. All statements from the posters are reported "as is" in terms of the use of English. Any grammatical inaccuracies have not been corrected to ensure authenticity in data.

Results

The findings present both preservice teachers' representations of scientific practices which are generated from their poster drawings. The analysis of preservice teachers' representations of scientific practices suggested five key categories which are varied in terms of linear and cyclic representations. The linear representations used the key concepts such as data and models in a stepwise and linear fashion, while the cyclic representations connected the concepts in a circle. The emerging categories were (a) linear to circular; (b) part linear-part circular to circular; (c) linear and hierarchical with new connections; (d) *from* conceptual to conceptual and epistemic, pre and post; and (e) linear to linear. In the following sections, we will describe each category as a case.

Table 1.1 The aims, main themes, and content of the preservice teacher training workshops

Workshop	Aim	Main theme	Content
1	To engage preservice teachers in a discussion on scientific practices	Introducing scientific practices	Preservice teachers:
			(a) Designed posters to represent their ideas about scientific practices at the beginning of the workshop before the taught content
			(b) Conducted "acids and bases" activity to situate scientific practices in the context of a school lesson example
			(c) Were introduced to BRH
			(d) Discussed activity in the light of BRH
2	To consolidate understanding of BRH and to start designing lesson plans	Adapting BRH to lesson planning	Preservice teachers:
			(a) Discussed components and relationships of scientific practices based on their activities
			(b) Incorporated their activities into lesson plans
			(c) Reflected upon their lesson plans in terms of teaching scientific practices
3	To engage the participants in reflection, model evaluation, and revision	Implementing pedagogical strategies to teach scientific practices	Preservice teachers:
			(a) Were introduced with three lesson plans with different pedagogical approaches (e.g., verification, open inquiry)
			(b) Evaluated the lesson plans in terms of scientific practices
			(c) Revised their previous lesson plans
			(d) Designed posters to represent their ideas about scientific practices

Case 1: Linear to Circular

In the pre-poster, there is a linear representation of scientific practices (see Fig. 1.3). The group classified scientific practices as "asking question, determining the problem, collecting data, constructing a hypothesis, testing hypothesis, analyzing the data, and communicating results" in a linear order. They determined "asking question" as the first step in a scientific procedure. The other practices follow each other

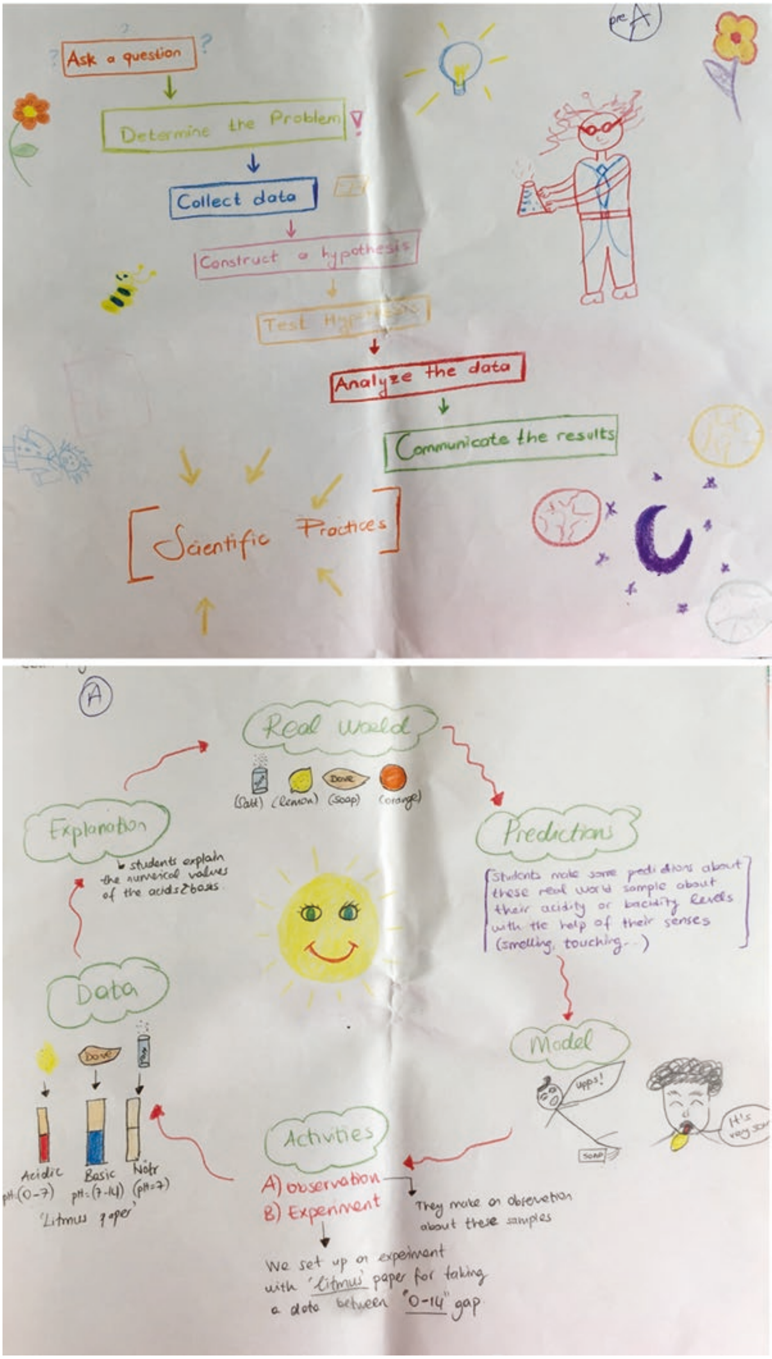
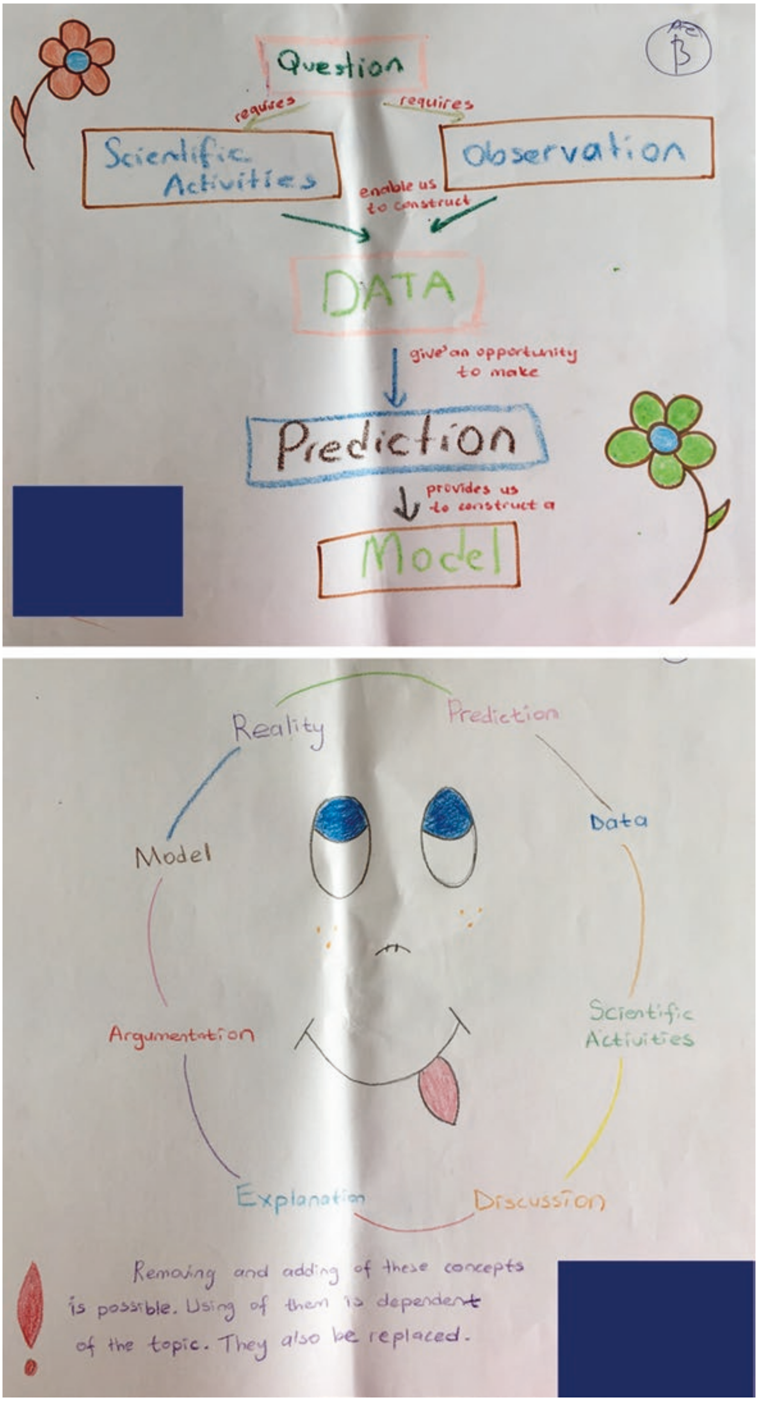


Fig. 1.3 Linear to circular representation of scientific practices

in an ordered fashion. However, in the poster produced after the intervention, the group characterized scientific practices as being different from the pre-intervention poster and presented these scientific practices in a circular representation. They also classified scientific practices as “real world, prediction, model, activity, data, and explanation.” In this circular representation of scientific practices, they used a chemistry context, specifically acids and bases. For example, they drew some objects such as salt, soap, lemon, and orange as examples of real world. They wrote “Students made some predictions about these real world samples about their acidity and basicity. Results with the help of their senses (smelling, touching…) were as examples of prediction.” For the model idea, they drew two pictures as examples of model. They modeled the senses of touching soap and tasting lemon. The group classified the activity as observation and experiment. For “observation,” they wrote “they make an observation about these samples.” For “experiment,” they wrote “we set up an experiment with litmus paper for taking a data between 0-14 gap.” For the data as scientific practice, the group drew the substances like lemon, soap, salt, and litmus papers for each substance. They also colored the litmus papers for each substance and wrote the pH values for each substance based on the color change of the litmus papers. That is to say, they presented some numerical and visual data as a result of observation and experiment activities. The group explained “explanation” as “students explain the numerical values of the acids & bases.” In addition, they drew a sun with a smiling face in the middle of this circular representation. All scientific practices follow each other with a one-way arrow in a circular system.

Case 2: Part Linear-Part Circular to Circular

The pre-poster shows part linear-part circular representation of scientific practices (see Fig. 1.4). The group starts with “question” as a scientific practice at the top of the representation. Then they classified “question” as “scientific activities” and “observation” and also specified question requires scientific activities and/or observation. They combined scientific activities and observation as “data” and stated “enable us to construct” on the arrows. Therefore, the group presented a circular representation of scientific practices at the top of their poster. The other part of the poster shows a linear representation of some scientific practices which are “data,” “prediction,” and “model.” The group connected “data” to “prediction” with the statement of “give an opportunity to make” and connected “prediction” to “model” with the statement of “provides us to construct a.” However, in the post-poster, the group classified scientific practices as “reality,” “model,” “argumentation,” “explanation,” “discussion,” “scientific activities,” “data,” and “prediction” in a circular system. They did not use any arrows in a specific way between these scientific practices; they just used lines between them. In addition, they wrote “Removing and adding of these concepts is possible. Using of them is dependent on the topic. They are also replaced.” under their drawing. They did not use any arrows between scientific practices.



Removing and adding of these concepts is possible. Using of them is dependent of the topic. They also be replaced.

[redacted]

Fig. 1.4 Part linear-part circular to circular representation of scientific practices

Case 3: Linear and Hierarchical with New Connections

The pre-poster starts with "discussion," "prediction," and "data" with a linear order (see Fig. 1.5). The group wrote "A problem or argument is determined" in the discussion part, and they also put some question marks here to show the problem. After discussion, prediction is made. Data are then generated. The "data" concept is connected to "scientific practices." At this point, they classified scientific practices as "modeling" and "experimenting." In "modeling," "observation" is made and in "experimenting," "explanation" is made. Then, the group finished by putting "Review of other scientists" at the bottom of the poster by combining observation and explanation. They did not use any arrows between the concepts in the poster, only lines between them. In the post-poster, the group starts with "real-world events," "problem," and "data." They connected real-world events and problem with the sentence of "by looking the nature, we can observe some changes and we would like to understand how it happens. It gives us a problem." They classified data as "model" and "prediction." They wrote "If it is possible, you build a model according to your data or previous research" as an explanation for the model. Then they combined data, model, and prediction concepts as "scientific practices." They put "explanation" as a final step in their representation and wrote "Our practice of science should give some explanation about the problem" as a connection between scientific practices and explanation. Additionally, there is another connection which is "review of previous scientific works" between prediction and explanation. They stated that review of previous scientific works can shape the prediction at the beginning. They connected review of previous scientific works and explanation with the sentence of "We should check our answer with previous works if they are consistence." They also put "argumentation" as another connection in the poster and stated that argumentation may occur at all steps.

Case 4: From Conceptual to Conceptual and Epistemic

In both pre- and post-posters, there is a science concept being used to explain particular phenomena (see Fig. 1.6). In other words, the group selected a concept (i.e., the water cycle) to turn into a cyclic representation. In the pre-poster, the emphasis is not on the epistemic features of scientific practices but rather on the conceptual domain related to the water cycle. In the pre-poster, there is a mix of the conceptual domain as well as the epistemic features related to scientific practices as described in the BRH. The group presented the concepts of ecosystem such as photosynthesis, vaporization, decomposers, glucose, CO_2, O_2, and N_2. For photosynthesis, they drew a sun, a tree with some arrows from sun to tree, from tree to gases like CO_2 and O_2. They also showed the cycle of N_2, considering decomposition of N_2 in air by plants in Earth. They drew a rabbit as a consumer of O_2 and exhaler of CO_2. In the post-poster, the group added new concepts such as "data," "inferring," "real world," "model," "argumentation," and "analyzing data." They considered all these concepts in terms of a pedagogical context. They wrote "data" after "real world." Under "data," they put photosynthesis, respiration, nitrification, and vaporization as examples. They also explained that all these components (i.e., photosynthesis, respiration, nitrification, and vaporization) are related to each other. And they stated that "teacher expects students to make connection among them" and named this as

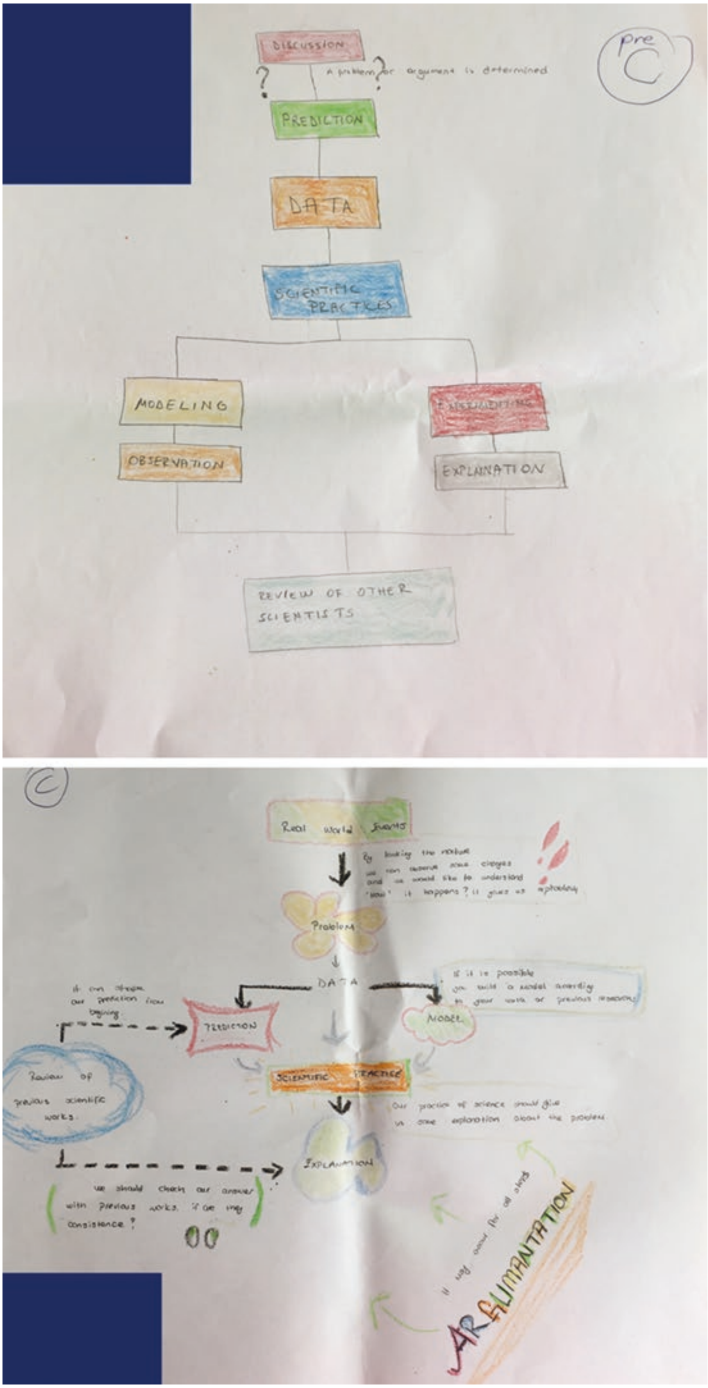


Fig. 1.5 Linear and hierarchical with new connection representation of scientific practices

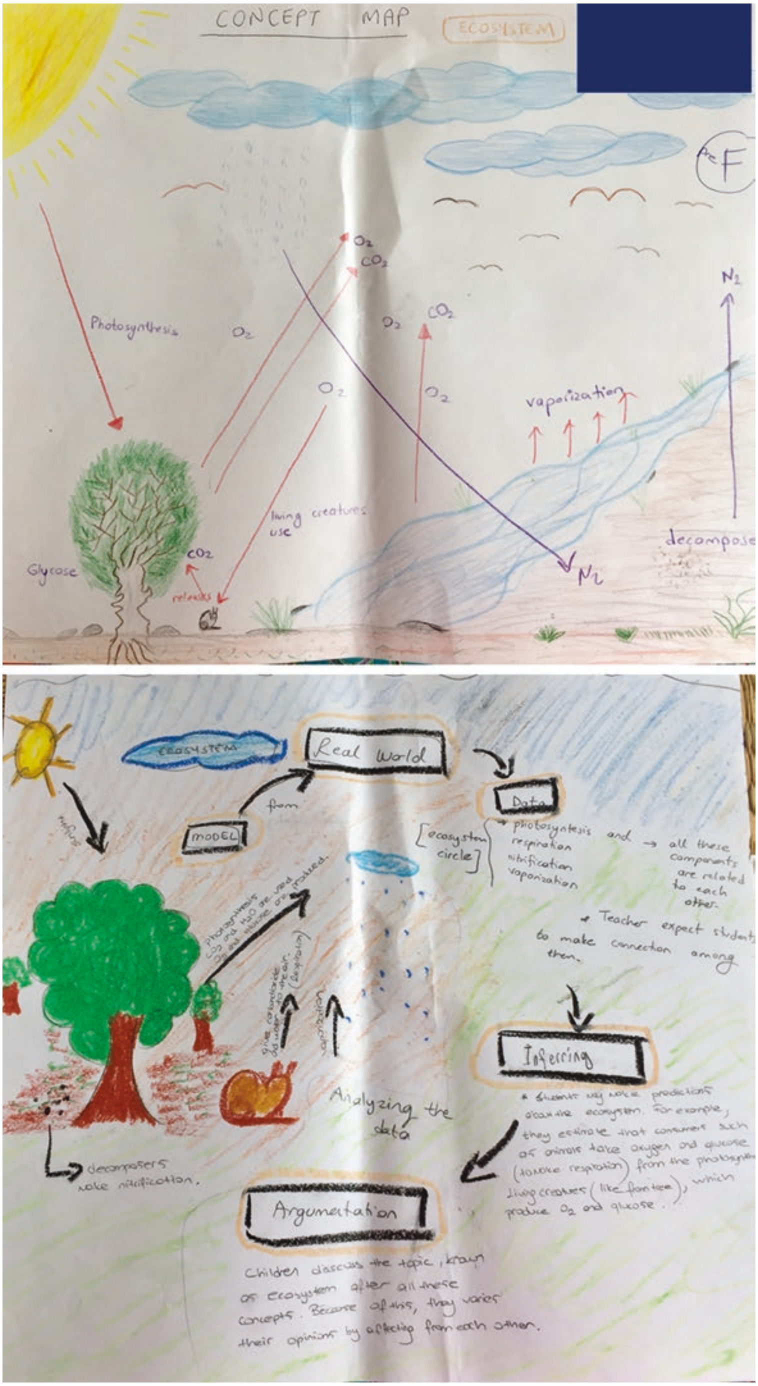


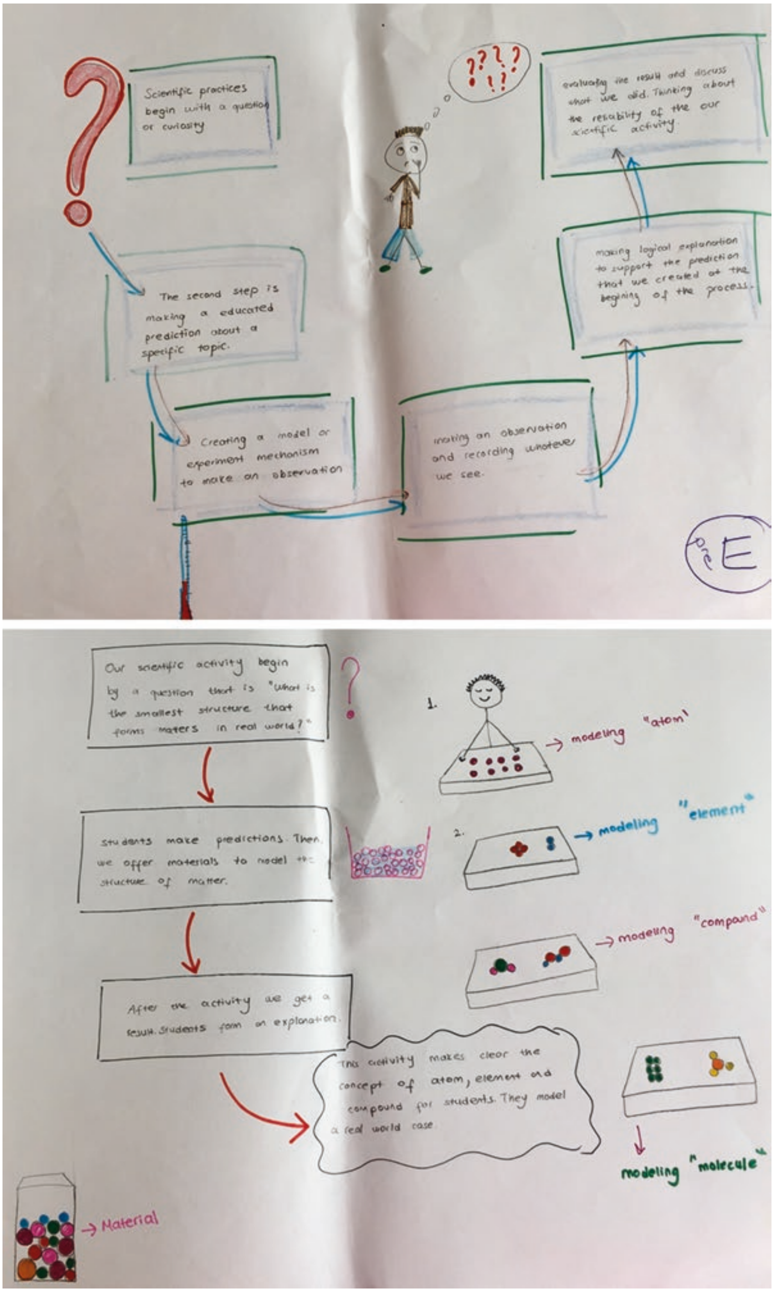
Fig. 1.6 From conceptual to conceptual and epistemic representation of scientific practices

"inferring" in the poster. Finally, they connected inferring to "argumentation" by the sentence of "Students may make predictions about the ecosystem. For example, they estimate that consumers such as animals take oxygen and glucose (to make respiration) from photosynthetic living creatures (like from tree), which produce oxygen and glucose." They also explained argumentation as "Children discuss the topic known as ecosystem after all these concepts. Because of this, they vary their opinions by affecting each other."

Case 5: Linear to Linear

The pre-poster shows a linear representation of scientific practices. The group classified scientific practices as six steps following each other (see Fig. 1.7). For the first step, they wrote "scientific practices begin with a question or curiosity" and put a big question mark here. The second step is "making an educated prediction about a specific topic." The third step is "creating a model or experiment mechanism to make an observation." The following step is "making an observation recording whatever we see." The next is "making logical explanation to support the prediction that we created at the beginning of the process." The last step is "evaluating the result and discussing what we did, and thinking about the reliability of our scientific activity." In the post-poster, the group shows again a linear representation of scientific practices but with a four-step classification and in a chemistry context which is different from the pre-poster. They formed their poster based on the topic of the atom. As the first step of scientific practices, they wrote "Our scientific activity begins with a question that is what is the smallest structure of that forms matters in real world?" Here, they considered both real world and asking questions from real world. As the second step, they wrote "Students make predictions. Then we offer materials to model the structure of the matter." Here, they considered both prediction and modeling. They also used models to explain this step. They drew pictures indicating atom, element, compound, and molecules. For example, for the atom model, they drew circles to represent atoms with same colors. For the element model, they drew two elements. One of these elements is composed of four atoms with red color; the other is composed of two atoms with blue color. And for the compound model, they drew two compounds. They used atoms with different colors to show compound. As the third step of scientific practices, they wrote "After the activity, we get a result. Students form an explanation." As the final step, the group wrote "This activity makes clear the concept of atom, element, and compound for students. They model a real world case."

Cases 1, 2, and 3 are examples of representations that suggest changes in preservice teachers' perceptions about scientific practices as more holistic and interconnected. Case 4 framed scientific practices as conceptual and epistemic in nature after the training when the emphasis was on the conceptual domain at the beginning. Finally, there was no change in Case 5 in terms of a switch from a linear to circular representation which would suggest a more holistic approach. In Cases 1, 4, and 5, there is inclusion of the pedagogical dimensions of scientific practices, while in Cases 2 and 3, this aspect is missing. The data suggest that the training intervention had some influence on holistic representation of scientific practices by preservice science teachers as illustrated in three of the five cases.



Scientific practices begin with a question or curiosity

The second step is making a educated prediction about a specific topic.

Creating a model or experiment mechanism to make an observation

making an observation and recording whatever we see.

making logical explanation to support the prediction that we created at the begining of the process.

evaluating the result and discuss what we did. Thinking about the reliability of the our scientific activity.

Our scientific activity begin by a question that is "What is the smallest structure that forms maters in real world?"

students make predictions. Then we offer materials to model the structure of matter.

After the activity we get a result. Students form an explanation.

This activity makes clear the concept of atom, element and compound for students. They model a real world case

Fig. 1.7 Linear to linear representation of scientific practices

Conclusions

The representations of groups of preservice teachers are identified on the basis of an analysis of their drawings. Investigation of the drawings suggested five key categories which showed qualitative differences between the posters drawn pre- and post-training intervention. The terms used to construct the drawings could be placed in various combinations to each other. Some preservice teachers chose to link these terms in a linear fashion, while others had more cyclic representations. In some instances hierarchies were used in combination with either linear or cyclic representations. The cognitive basis of representations is well established (Chi 2006; Novak 1990) suggesting that some of the representations might indicate quality in reasoning. Although changes have been observed in preservice science teachers' representations of scientific practices, it is possible that the participants simply recalled the BRH and responded by using the tool without deeper understanding. Although this is a possibility, the fact that they have applied the BRH to a new content area often either supplementing the figure with explanatory text or using the BRH in a new content area is a promising indicator of improved understanding. Data on pre- and post-interviews with the participants are currently being carried out which will help further illustrate the extent of the impact of the intervention on preservice science teachers' understanding of scientific practices. The study reported here will have broader interest to colleagues who are studying scientific practices in the context of teaching and learning of science in particular in terms of enhancement of science teaching.

The chapter contributes to the literature on scientific practices in particular and NOS in general given the broader conceptualization of NOS in our work. Our account of NOS (Erduran and Dagher 2014a) is based on the family resemblance approach (FRA) which enables the inclusion of scientific practices as a dimension of NOS. As the FRA is a relatively new concept in NOS studies in science education (i.e., Dagher and Erduran 2016; Dagher et al. 2017; Erduran and Dagher 2014b; Kaya and Erduran 2016; and Erduran 2015; Irzik and Nola 2014), empirical testing of ideas based on the FRA has been scarce. In this sense, the teacher training project described in the chapter contributes to the empirical articulation of FRA-based NOS accounts and illustrates the utility of the BRH as a potentially useful heuristic for science teacher education. As the study illustrates, the BRH has been effectively used to inform the design of a series of preservice teacher training workshops. BRH has furthermore been useful in serving as a tool for evaluating the representations of preservice science teachers in conceptualizing scientific practices. Given the vast amount of work in the science education research literature on the linear and mythical depiction of the scientific method (Windschitl et al. 2008; Wivagg and Allchin 2002), the study reported here is promising in influencing the perceptions of preservice teachers' perceptions of scientific practices in a more holistic and circular sense, even though not all groups made progress in this respect. The chapter will be relevant for researchers who are interested not only in the themes of NOS and scientific practices but also in science teacher education. A new project called "Whole Science" led by Kaya and Erduran (www.natureofscience.net) is underway to integrate all components of NOS from a FRA perspective in preservice teacher education, providing further evidence on holistic accounts of NOS in science education.

Acknowledgment The project reported in this paper was led by Sibel Erduran whose tenure at Bogazici University, Istanbul, Turkey, was supported by a TUBITAK and European Union Marie Curie Co-Fund Brain Circulation Scheme Fellowship (291762/2236). The project was entitled "Revisiting Scientific Inquiry in the Classroom: Towards an Interdisciplinary Framework for Science Teaching and Learning." The project team included Ebru Z. Mugaloglu, Deniz Saribas, and Gaye Ceyhan who contributed to the broader project. An earlier version of this paper was presented as part of a keynote lecture by Sibel Erduran at the International Science Education Conference held in Singapore in November 2014.

Appendix 1: Acids and Bases Activity (From Erduran 1999)

Testing Acids and Bases by Your Senses!

Part 1 In this activity, you will test different substances with our senses. You will see, smell, taste, and touch them. In the spaces provided in the table, please describe your experience. Guess if you think they contain acids, bases, or neither.

To do these tests, take a sample of each substance using toothpicks. Once you finish your test, break and dispose of the toothpick. For each test, use a fresh toothpick and wash your mouth with cold water.

	Lemons	Vinegar	Soap	Unsweetened chocolate	Baking powder
Sight					
Smell					
Touch					
Taste					
Contains acid/base/neither					

Part 2 In this activity, you will do more tests with some of the substances from Part 1. This time, you will add water to them and then test them.

First add ten drops of water to each liquid and gently stir. Take a few drops of each liquid using toothpicks. Once you finish your test, break and dispose of the toothpick. For each test, use a fresh toothpick and wash your mouth with cold water. Write down your observations in the following table.

Then put ten more drops to the same liquid and test. Again, record your observations. Finally, add ten more drops and write down your observations.

Tell if you think each substance is acid, base, or neither.

	Lemons	Vinegar	Soap	Unsweetened chocolate	Baking powder
Sight					
Smell					
Touch					
Taste					
Contains acid/base/neither					

Part 3 Draw a picture to tell what happens when you put more and more water to the liquids in Part 2. Your picture is to explain any change that you see, smell, touch, and taste.

Picture to show what happens when you put more and more water in an acid.

Picture to show what happens when you put more and more water in a base.

References

AAAS (1989) Science for all Americans. American Association for the Advancement of Science, Washington, DC

Abd-El-Khalick F (2012) Examining the sources for our understandings about science: enduring conflations and critical issues in research on nature of science in science education. Int J Sci Educ 34(3):353–374

Abd-El-Khalick F, Lederman N (2000) Improving science teachers' conceptions of nature of science: a critical review of the literature. Int J Sci Educ 22:665–701

Allchin D (2011) Evaluating knowledge of the nature of (whole) science. Sci Educ 95(3):518–542

Alters BJ (1997) Whose nature of science? J Res Sci Teach 34(1):39–55

Chang Y, Chang C, Tseng Y (2010) Trends of science education research: an automatic content analysis. J Sci Educ Technol 19:315–332

Chi MTH (2006) Methods to assess the representations of experts' and novices' knowledge. In: Ericsson KA, Charness N, Feltovich P, Hoffman R (eds) Cambridge handbook of expertise and expert performance. Cambridge University Press, Cambridge, pp 167–184

Dagher ZR, Erduran S (2016) Reconceptualising the nature of science: why does it matter? Sci & Educ. doi:10.1007/s11191-015-9800-8

Dagher Z, Erduran S, Kaya E, BouJaoude S (2017) Supporting science teachers' inclusion of scientific practices in Lebanon. Paper presented at the annual meeting of NARST: a worldwide organization for improving science teaching and learning through research, Baltimore, MD, April 14–17

Dagher ZR, Erduran S (2017) Abandoning patchwork approaches to nature of science in science education. Can J Sci Math Technol Educ 17(1):46–52

Erduran S (1999) Merging curriculum design with chemical epistemology: a case of learning chemistry through modeling. Unpublished PhD Dissertation, Nashville, Vanderbilt University, TN, USA

Erduran S (2017) Visualising the nature of science: beyond textual pieces to holistic Images in science education. In: Hahl K, Juuti K, Lampiselkä J, Lavonen J, Uitto A (eds) Cognitive and Affective Aspects in Science Education Research: Selected Papers from the ESERA 2015 Conference. Springer, Dordrecht, pp 15–30

Erduran S, Mugaloglu E, Kaya E, Saribas D, Ceyhan G, Dagher Z (2016) Learning to teach scientific practices. CPD resource. University of Limerick, Limerick

Erduran S (2014) A holistic approach to the atom. Educacio Quimica EduQ 19:39–42. ISSN 2013-1755

Erduran S, Dagher Z (2014a) Reconceptualizing the nature of science for science education: scientific knowledge, practices and other family categories. Springer, Dordrecht

Erduran S, Dagher Z (2014b) Regaining focus in Irish junior cycle science: potential new directions for curriculum and assessment development on nature of science. Irish Educ Stud 33(4):335–350

Grandy R, Duschl R (2008) Consensus: expanding the scientific method and school science. In: Duschl R, Grandy R (eds) Teaching scientific inquiry: recommendations for research and implementation. Sense Publishers, Rotterdam, pp 304–325

Irzik G, Nola R (2014) New directions for nature of science research. In: Matthews M (ed) International handbook of research in history, philosophy and science teaching. Springer, Dordrecht, pp 999–1021

Kaya E, Erduran S (2015) Missing pieces and holes in the Turkish middle school science curriculum: towards a reconceptualized holistic account of NOS. Paper presented at the international history, philosophy and science teaching biennial conference, Rio de Janeiro, Brazil, July 22–25

Kaya E, Erduran S (2016) From FRA to RFN, or how the family resemblance approach can be transformed for science curriculum analysis on nature of science. Sci Educ 25(9–10):1115–1133

Lederman NG (1992) Students' and teachers' conceptions of the nature of science: review of the research. J Res Sci Teach 29(4):331–359

Lederman N (2007) Nature of science: past, present, future. In: Abell S, Lederman N (eds) Handbook of research on science education. Lawrence Erlbaum, Mahwah, pp 831–879

Lederman N, Abd-El-Khalick F, Bell R, Schwartz R (2002) Views *of nature of science* questionnaire: toward valid and meaningful assessment *of l*earners' conceptions *of nature of science*. J Res Sci Teach 39:497–521

Matthews M (2012) Changing the focus: from nature of science (NOS) to features of science (FOS). In: Khine MS (ed) Advances in nature of science research. Springer, Dordrecht, pp 3–26

McComas WF, Olson JK (1998) The nature of science in international science education standards documents. In: McComas (ed) The nature of science in science education: rationales and strategies. Kluwer Academic Publishers, New York, pp 41–52

McComas WF, Clough MP, Almazroa H (1998) The role and character of the nature of science in science education. Sci & Educ 7(6):511–532

National Council for Curriculum and Assessment (NCCA) (2015) Specification for junior cycle science, November, Dublin

National Research Council (1996) National science education standards. National Academies Press, Washington, DC

National Research Council (2012) A framework for K-12 science education: practices, crosscutting concepts, and core ideas. National Academies Press, Washington, DC

NGSS Lead States (2013) Next generation science standards: for states, by states. Appendix H. Retrieved from http://www.nextgenscience.org/next-generation-science-standards

Novak JD (1990) Concept maps and vee diagrams: two metacognitive tools for science and mathematics education. Instr Sci 19:29–52

Windschitl M, Thompson J, Brown M (2008) Beyond the scientific method: model-based inquiry as a new paradigm of preference for school science investigations. Sci Educ 92:941–967

Wivagg D, Allchin D (2002) The dogma of “the” scientific method. Am Biol Teach 69(9):645–646

Zeidler DL, Walker KA, Ackett WA, Simmons ML (2002) Tangled up in views: beliefs in the nature of science and responses to socioscientific dilemmas. Sci Educ 86(3):343–367

Zembal-Saul C (2009) Learning to teach elementary school science as argument. Sci Educ 93(4):687–719

Chapter 2
Introducing Modelling into School Science

John K. Gilbert and Rosária Justi

Abstract Arguments for the importance of modelling in school science are rehearsed. In the light of the historical neglect of this aspect of the school curriculum, there is a need to develop and implement successful teaching strategies. A Model of Modelling that has been successfully implemented is presented, and the requirements for its widespread introduction are outlined. The challenges that have to be met for the success in this enterprise are outlined. The limited evidence available on the meeting of these challenges in Far East countries, as reported in the international press, is reviewed.

Teaching Modelling in School Science

The word 'model' can be thought in scientific contexts as meaning an accessible representation of theory and of data directly related to the world as experienced. Put another way, models have been described as 'mediating between theory and data' (Morrison and Morgan 1999). Modelling is the complex operation involved in producing and validating such models. Learning modelling should be an important aspect of school science education, for two reasons. Firstly, modelling is a key aspect of all thinking, and so developing the skills of thinking must therefore form part of all formal education. Secondly, modelling is a key aspect of the nature of science, that is, how science is conducted and validated. Learning about the nature of science has, in recent years, come to be seen as a vital component of science education (Abd-El-Khalick 2005; Allchin 2013), hence the need for a clearer focus on modelling.

There are several major handicaps to realising the importance of modelling in school science. Firstly, ever since science education began to be formally provided in schools in the mid-eighteenth century, the focus of curricula and of public examinations has been on content – the learning of the separate facts and overarching

---

J.K. Gilbert (✉)
The University of Reading, Reading, UK
e-mail: john.k.gilbert@btinternet.com

R. Justi
Universidade Federal de Minas Gerais, Belo Horizonte, Brazil

J. Yeo et al. (eds.), *Science Education Research and Practice in Asia-Pacific and Beyond*, DOI 10.1007/978-981-10-5149-4_2

concepts of science. As a consequence, teaching schemes focus on the nature of science, including modelling, have not been generally available. Secondly, it has become evident that the personal education and professional training of almost all science teachers have grossly neglected the theme of nature of science in general and of modelling in particular. Taken together, these two handicaps have resulted in little effective widespread teaching and learning of the nature of science and, inevitably, of modelling (Lederman and Lederman 2014).

Approaches and Conditions to the Teaching and Learning of Modelling

A principled approach to the introduction of the teaching and learning of modelling in science has, following its extensive trial in a limited range of school contexts, been reported in full (Gilbert and Justi 2016). However, attempts to implement the teaching of modelling in a wide variety of school contexts will, based on the severe and sustained problems that other teaching innovations have met (Van den Akker 1998), require that close attention be paid to particular aspects of what has to be done. In the three sections that follow, we summarise the main component of the Model of Modelling that forms the central theme of the work reported in Gilbert and Justi (2016), identify the key issues that may arise during its introduction into conventional – content-driven – classrooms, and then suggest ways in which progress towards effective implementation of teaching based on the model can be made. Finally, we summarise and evaluate the work on modelling that has been both undertaken in East Asia and published in international-level journals, suggesting some ways forward in that context.

The Model of Modelling

Although we recognise that modelling is a dynamic process and that it is impossible to define a precise method for performing it, we have identified some stages that seem important in order to generate a model that will be valid in any given context. We organised such stages into a representation which we called a model of modelling (Justi and Gilbert 2002). The most recent form of our Model of Modelling is given in Fig. 2.1. For more details about its foundations and structure, please see Gilbert and Justi (2016).

Modelling-based teaching (MBT) is the phrase that has been used in the literature to characterise teaching situations in which students are provided with an opportunity to create and use models (Clement and Rea-Ramirez 2008; Gobert and Buckley 2000; Maia and Justi 2009; Svoboda and Passmore 2013). From the perspective of the model of modelling, it entails four kinds of activity, each of which requires mental (and sometimes physical) engagement by students. The activities are outlined in the following four sections:

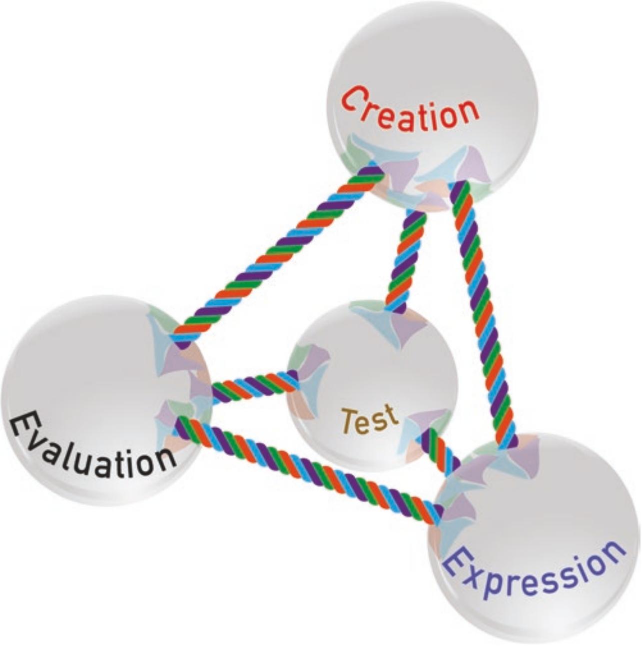


Fig. 2.1 The Model of Modelling (Gilbert and Justi 2016, p. 36)

The Creation of an Initial Mental Model

Although there is no universally agreed definition of ‘mental model’, the phrase can, for our purposes, refer to ‘a representation in the mind of a person of some aspect of the world as experienced’. The action of creating a mental model has four components or elements. These are:

- Taking a decision on the aims of the model, that is, deciding on the type of explanation it is intended to facilitate. The possible types of explanation are contextual (naming what is being investigated), intentional (stating why an explanation is needed), descriptive (measuring the properties of the model), interpretative (describing the model in full), causal (stating why the model behaves as it does), and predictive (thinking what the behaviours of the model would be in different circumstances) (Gilbert et al. 1998). In the classroom teaching context, the decision on the aims of a model is often taken by the teacher and, at best, communicated to students.
- Acquiring experience of the phenomenon to be modelled. Experience may be gained either directly, by laboratory or field work on it, or indirectly, for example, by viewing a video of its behaviour or by reading something written about it by someone else.

- Relating the aims for the model to the experience of the phenomenon. This involves matching the two, that is, deciding the explanation type(s) that would lead to the aim(s) of the mental model being achieved.
- Using analogical reasoning approach to argumentation (Treagust et al. 1998) in order to produce the initial version of the mental model, which may be called the 'proto-model'.

Expression of the Proto-model

This involves taking actions on the proto-model in order to make it communicable to other people. Three elements are involved here, which are:

- Producing a 'visualisation' of the proto-model, which makes it possible to 'see' the mental model in your 'mind's eye' (Gilbert 2005).
- Expressing the proto-model in one of the five main 'modes of representation' which are possible (i.e. the concrete/material, verbal, visual, symbolic, virtual). Each of these has sub-modes that vary in their capacity to represent and so to facilitate visualisation (Gilbert et al. 1998). Doing so places a proto-model in the realm of common experience.
- Adapting the model that has been expressed (the 'expressed model') in the light of the aims underlying its creation and of the experience previously had of the phenomenon. The intention is to make it more closely meet those aims.

Testing the Model

A major component of scientific methodology is the requirement that a proposed explanation, based on a model, be used to see the extent of its match with the relevant aspect of the behaviour of the phenomenon.

This testing of the model has four elements, which are:

- Planning and conducting 'thought experimentation' using the expressed model. This has all the usual components of practical work but is carried out mentally rather than empirically (Gilbert and Reiner 2000).
- Planning and conducting 'empirical experimentation'. To see if the thought experimentation has had a positive outcome to some degree (i.e. the predicted results had been obtained), and if the empirical (laboratory) versions of the experiments can be successfully carried out.
- Critically evaluating the results of both the 'thought' and the 'empirical' experiments.
- Modifying the model if needed, assuming that the thought and/or empirical experimental results were reasonably satisfactory. However, if the experiments produced unsatisfactory results, another proto-model will have to be created, and the procedure started again.

Evaluation of the Model

The evaluation of the model involves comparing the degree to which behaviour based on it agrees with that of the phenomenon itself.

Evaluation involves three elements which are:

- Establishing the limitations of the model in terms of its declared aims. This may be done by answering the following question: to what extent does the model properly play the role that was expected of it?
- Establishing the scope of the model by using it for similar purposes in respect of allied phenomena. This capacity for 'transferability' is an important indicator of the value of a model (Gilbert 2006).
- Convincing others (e.g. fellow students) of the validity of the model that has been expressed. The skills of argumentation are vital here (Mendonça and Justi 2013; Passmore and Svoboda 2012).

The existence of these three elements means that a single teaching activity in which students are only asked to reproduce a pre-existing model cannot be characterised as providing an MBT context.

Studies that investigate the involvement of students in all of these sorts of activity have shown that they collectively provide an opportunity to experience a more authentic science education (Gilbert 2004) and have contributed to an improvement in their learning of science and about science (for instance, Clement and Rea-Ramirez 2008; Maia and Justi 2009; Mendonça and Justi 2011; Prins et al. 2009; Windschitl et al. 2008). However, providing the circumstances for this to be achieved does require the presence of a particular set of classroom conditions. To emphasise this importance, we summarise the complete list in the next section.

The Requirements for Successful Modelling-Based Teaching

The several general social, psychological, and pragmatic conditions that have to be met if the Model of Modelling is to have a chance of being successfully implemented in a science class are:

- MBT must be implemented in respect of a phenomenon for which the students might have had practical experience (directly or indirectly) and which is, or might be, of interest to them.
- The class should seek a particular type of explanation, this enabling the students to know *why* they are learning about the phenomenon.
- The teaching should involve a phenomenon or idea for which the students do not already know of an established model.
- The aims of the activity (the purposes for which the model is to be developed) should be capable of engaging the sustained interest and commitment of the class.

- The class must consist of a reasonable number of students so that extensive interactions between students working in small groups and between the teacher and the groups are feasible.
- The class must have a pedagogic history characterised by extensive two-way interaction between the teacher and the students, especially when initiated by students (Mortimer and Scott 2003).
- Each session for the class must be of sufficient duration to enable discussion-led progress to be made from interactions between students in small groups, between students from distinct groups in whole class discussions, and between students and the teacher.
- Students must already have had extensive experience of attempting to persuade others of the value of their ideas (Berland and Reiser 2010; Jiménez-Aleixandre and Erduran 2008; Jiménez-Aleixandre and Pereiro Muñoz 2002; Sampson et al. 2011).

The general pedagogic conditions will be met if the students have already had extensive experience of the skills of:

- Relating the aims that the class are addressing to the theoretical and empirical decisions that are being taken and implemented in the class.
- Engaging in analogical reasoning (Mozzer and Justi 2011; Treagust et al. 1998).
- Producing visualisations (Gilbert 2005).
- Planning and conducting thought experiments (Gilbert and Reiner 2000).
- Participating in argumentative situations (Jiménez-Aleixandre 2008; Sampson and Clarke 2008).

The above conditions are demanding, and in many school contexts, there will be problems in meeting them. Such problems will arise for a series of reasons. Teachers may lack the knowledge necessary to implement MBT. Parents may complain about the introduction of the approach because of their ignorance and/or misunderstandings about the MBT approach and its possible outcomes in terms of students' development in traditional content transmission terms. However, the excellent outcomes reported in empirical studies conducted in regular classrooms where most of the above conditions were satisfied (for more details, see Gilbert and Justi 2016) show that it is worth facing the challenges of providing (or improving) the necessary conditions in schools.

Problems in Introducing and Sustaining Modelling-Based Learning

The usual conditions for the provision of science teaching in school science – what Thomas Kuhn calls 'the normal paradigm' (Kuhn 2012) – contain several elements that are not supportive of modelling-based classes. These are the existence of:

- Very large class sizes. Meaningful interaction between and with all the students tends to not be feasible in these circumstances.
- A lack of experience of group work. The problems of managing a class consisting of many groups, when students have no strong interest in the work being done, often preclude the extensive use of such groups.
- A lack of meaningful interactions within the class. The above two conditions mean that many, if not most, interactions are initiated by the teacher and are of the question-response-evaluation format.
- There is no tradition in many science classes of the conduct of analogical thinking, of the explicit creation of visualisations, and of the explicit use of the 'modes of representation'.
- The underuse of argumentation by students with other students.

On the other hand, some studies conducted in regular classes composed of more than 30 students, but in which the teacher had the knowledge and skills needed to implement MBT activities, show that the participation in those activities also support students' learning of, and engagement in, analogical thinking (Mozzer and Justi 2011), producing visualisations (Gilbert et al. 2010; Oliveira et al. 2015), planning and conducting 'thought experiments' (Maia and Justi 2009; Mendonça and Justi 2011), and participating in argumentative situations (Mendonça and Justi 2013; Oliveira et al. 2015). Therefore, the 'normal' paradigm of school science teaching cannot be viewed as a barrier to the implementation of an MBT approach to science education. In fact, it seems that the main obstacles to the implementation of an MBT approach in science classrooms are the teacher's willingness and knowledge about how to do so. In the case of any education innovation, the teacher is ultimately responsible for implementing it. Therefore, the challenges of educating teachers about contemporary perspectives on science education and in supporting their innovatory work seem to really be the key to changing the 'normal' paradigm of school science teaching.

Strategies for Introducing and Sustaining Modelling-Based Teaching and Learning

A number of strategies can be adopted so that not only is the initial phased introduction to modelling successful, but it becomes an established style of teaching and learning. These are:

- Increasing the reciprocal extent and broadening the range of teacher-student and student-student interactions.
- Explicit teaching of the use of analogical reasoning in science and science education.

- Explicit teaching of the codes of representation (the aspects of a model that can be clearly represented in a particular mode) of the various modes of representation (whether the visual, verbal, concrete material, diagrammatic).
- Explicit teaching of the skills of visualisation.
- Explicit teaching about argumentation and its role in the production, communication and discussion of scientific knowledge.
- Making clear the relations between models and modelling and essential attributes of scientific knowledge.
- Starting by 'teaching the nature of models' and working towards modelling-based teaching.

Modelling-based science teaching is gradually being introduced throughout the world, including in Far East countries.

Modelling in School Science in East Asian Countries

Many East Asian countries are introducing 'nature of science' and 'inquiry-based teaching', with their implicit inclusion of modelling as a topic and skill set, into their school science curricula. A very recent overview of science education research and practice in East Asia, as published in international and national science education journals (Lin et al. 2016), included such data under two headings: 'history and philosophy of science and nature of science (HPNOS) ' and 'learning inquiry and practical' (LIP). That data is presented by country, the number of papers being followed by the percentage of that type of paper in all science education research output in a given country, in Table 2.1.

These numbers suggest that publishing papers on modelling may not yet have achieved a degree of priority, but the situation is not clear. Looking more closely at the international-level literature specifically in science education, we identified only a few papers apparently explicitly concerned with modelling that had East Asian authors: Chiu et al. (2002), Zhang et al. (2006), Wu (2010), Lin and Chiu (2010), Oh and Oh (2011), Chang and Chang (2013), Wu et al. (2013), Lin (2014), Liu et al. (2014), and Cheng and Lin (2015).

Although there are overlaps between papers, the following modelling-related themes are present.

Table 2.1 East Asia publications that may have dealt with models and modelling

Country	HPNOS	LIP
China	27 (4.3%)	87 (13.8%)
Japan	8 (0.8%)	59 (6.2%)
Korea	117 (5.4%)	300 (13.8%)
Taiwan	25 (7.8%)	24 (7.5%)

Abstracted from Song et al. (2016, Table 6, p. 148–150)

Teacher Knowledge About Modelling

The study into teachers' knowledge reported in Lin (2014) looked into the situation in Taiwan and in respect of 'elementary schools'. It is not clear why such a focus was decided upon, perhaps because modelling is first encountered in that (undefined) age phase. More informatively, the knowledge of 'specialist' and 'non-specialist' teachers was compared: this is helpful, because the latter group is presumably the more numerous. Using primarily a Likert scale questionnaire, which by its very nature just required respondents to recognise statements about modelling, the knowledge of both groups was found to be adequate. Follow-up interviews showed, as one would expect, that only the specialist teachers had the pedagogic content knowledge required for successful teaching of the practical skills involved. Improved pre- and in-service education was suggested.

In an interesting study, Lin and Chiu (2010) administered a pre- and post-instruction test on acids and bases and focused the teaching of this topic through a modelling approach to a class of ninth grade students in Taiwan. From the pretest results, small groups of low and high achievers were identified and interviewed. Following instruction, which was recorded, both groups were also reinterviewed. The results show that the teacher made correct interpretations of the pre-instruction understandings of the high-achieving group but not that of the low-achieving group. In the latter case, the teacher's subsequent actions just reinforced the low-achieving group's pre-instruction misunderstandings. This study seems to reinforce the notion that teachers' pedagogic content knowledge must include a grasp of students' pre-instruction knowledge about modelling if this is to be the focus of instruction. This knowledge would enable the teacher to provide appropriate support for students in their reconstruction and construction of models.

The efficacy of this support was shown in a study by Chiu et al. (2002) of tenth grade students in Taiwan, working on the theme of chemical equilibrium, where the teacher's 'cognitive apprenticeship' engagement during practical work enabled acceptable models of the phenomenon to be created. Indeed, the teachers' classroom practice corresponded fairly closely to the norms of practice as outlined earlier.

These three studies show that, when teaching through and about modelling, teachers must have a sound understanding of the approach, must be aware of what their students understand about the phenomenon being addressed, and must behave supportively rather than deductively.

The Teaching of Modelling

That a focus on modelling has only recently begun to emerge in East Asian countries is shown by the fact that a fairly recent review of the fields of models and modelling in science education (Oh and Oh 2011) concentrates on the former rather than on the latter. There is a general temptation in research and development work on science education to both concentrate on development before sufficient research has been undertaken and to proceed without a due sensitivity to the cultural context of any future general (i.e. multicultural) application. An early paper on the use of a computer-managed modelling kit which has an apparently East Asian authorship fails to identify the national context in which the work was undertaken (Zhang et al. 2006). Following the long tradition in East Asian countries to learn from texts, a recent study (Jong et al. 2015) investigates the effect of students reading a text that explicitly discussed the specific stages of modelling. This was done with the exemplification of the ideal gas law through the use of modelling competences (assumed by the authors to be “the thinking skills that students use to generate, validate, revise, and reconstruct their mental models” (Jong et al. 2015, p. 988)). It shows that the new educational demand may be met, at least in part, by traditional approaches.

The Skills Involved in Modelling

The fact that it is ‘early days’ in research and development concerned with modelling in East Asia is shown by the very fragmentary attention so far paid to the multiple skills, as outlined in this chapter, that are involved in it. The necessity of a good grasp on the ‘nature of a scientific model’ by students was shown in the study of ninth graders in Taiwan, whose performance in this respect was very variable (Cheng and Lin 2015). The ability of tenth grade students in Hong Kong to visualise the various sub-modes of diagrammatic representation that are used in human biology has been shown to their attitudes in general to this type of work (Liu et al. 2014). The paper by Chang and Chang (2013), showing that eighth grade students in Taiwan, when provided with a scaffolded programme of support, learnt the skills of evaluating expert- and peer-generated models, may set a precedent for the change of attitudes that seem to be called for.

Fundamental Research into Modelling

Given the sparseness of fairly straightforward empirical work on modelling in East Asia so far, it is hardly surprising that little fundamental work, which is inherently more demanding, has been done. A notable exception has been the work by Wu, who has been conducting interesting studies on students’ visualisation and modelling in the last decade. For instance, in one of her studies (Wu 2010), students were really involved in learning to construct a model de novo (Justi and Gilbert 2002). This arose from their engagement in the epistemic practices involved in modelling when they used a technology-enhanced learning environment (that included a computer-based modelling tool and was developed from the analysis of novice and experts modelling practices) when learning about air quality. The students had neither previous experience with modelling nor previous knowledge about the topic. The results of the study (supported by substantial data) show that most of them developed both the skills of modelling and conceptual knowledge about modelling. However, independently of the results, this study has the merits of providing students with nearly authentic conditions in which to create their models[1] and analysing the process of students' development of modelling practices. From both aspects, the study generated knowledge that may contribute to the research in the area and support new relevant questions to be investigated.

Other Matters

The brief literature review given above, albeit only focusing on papers that appeared in international journals, drew very heavily of work with a Taiwanese authorship. It may be that work elsewhere in East Asia is still only published in national journals. We would encourage the authors of such work to make it available to international audiences. Three other matters came to our attention on which we would encourage further work:

- Almost all the studies reported were concerned with students in grades 8–10 and their teachers. It may be that modelling only enters curricula at this stage or that gaining access to such students for research purposes is easiest in those grades. However, the skills involved in modelling are both many and complex. The ability to model must surely develop slowly in even the most advantageous classrooms. Surely there is a need for studies of students of grade 7 and below as well as of those in grades 10–12 and university students, better still, longitudinal studies across the whole school and university science curriculum.
- Computer-based modelling kits are becoming widely available. Whilst these are attractive because of their apparent efficiency of time use, we would encourage work that sought to build bridges of understanding about modelling with and without the use of such systems. Guidelines from doing this could be drawn up from the studies conducted by Wu and her group (Wu 2010; Wu et al. 2013). Our ambition is that scientific modelling becomes a widespread mental skill that can be deployed in any physical environment.
- As previously emphasised, science MBT may not be introduced into East Asian schools if teachers do not have the required knowledge and were not convinced about its effectiveness in supporting students' learning *of* and *about* science. Therefore, we view the planning of teachers' education activities from a modelling-based approach as very important, together with the conduct of studies on (i) the development of teachers' knowledge about modelling and MBT and

---

[1] The author recognises that one of the limitations of her study is that the computer modelling tool does not allow students to create any variable they want. But she also informs the reader that such a limitation would be addressed in a new version of the tool.

(ii) the way teachers integrate such knowledge into actions in regular classes. The current literature published by authors from other countries (discussed in chapter 11 of our recent book (Gilbert and Justi 2016)) may help those interested in facing this challenge.

Some Progressive Changes to Teaching

In the meantime, and assuming that teachers understand the basics of MBT, there are a number of avenues for the development of teaching practice that would support the progressive introduction of modelling-based teaching into schools. These are:

- Seeking to have larger blocks of time for at least some lessons, for this would accommodate sustained work.
- Expanding the use of group work in teaching.
- Expanding the use of question-and-answer approaches to teaching.
- Introducing the study of examples of phenomena in which the students may be genuinely interested and for which they have not already been taught standard models.
- Introducing and providing sustained practice in the notion of 'explanation' in science.
- Providing explicit instruction and practice in the use of analogy in seeking explanations.
- Providing extended experience in the production of visualisations of mental models and their communication to others (students, the teacher).
- Introducing and providing extensive opportunities to construct and run 'thought experiments'.

References

Abd-El-Khalick F (2005) Developing deeper understanding of nature of science: the impact of philosophy of science courses on pre-service teachers' views and instructional planning. Int J Sci Educ 27(1):15–42

Allchin D (2013) Teaching the nature of science: perspectives & resources. SHiPS Educational Press, Saint Paul

Berland LK, Reiser BJ (2010) Classroom communities' adaptations of the practice of scientific argumentation. Sci Educ 95(2):191–216

Chang H-Y, Chang H-C (2013) Scaffolding students' online critiquing of experts- and peer-generated molecular models of chemical reactions. Int J Sci Educ 35(12):2028–2056

Cheng M-F, Lin J-L (2015) Investigating the relationship between students' views of scientific models and their development of models. Int J Sci Educ 37(15):2435–2475

Chiu M-H, Chou C-C, Liu C-J (2002) Dynamic processes of conceptual change: analysis of constructing mental models of chemical equilibrium. J Res Sci Teach 39(8):688–712

Clement JJ, Rea-Ramirez MA (2008) Model based learning and instruction in science. Springer, Dordrecht

Gilbert JK (2004) Models and modelling: routes to a more authentic science education. Int J Sci Math Educ 2:115–130

Gilbert JK (2005) Visualisation: a metacognitive skill in science and science education. In: Gilbert JK (ed) Visualisation in science education. Springer, Dordrecht, pp 9–28

Gilbert JK (2006) On the nature of 'context' in chemical education. Int J Sci Educ 28(9):957–976

Gilbert JK, Justi R (2016) Modelling-based teaching in science education. Springer International Publishing, Basel

Gilbert JK, Reiner M (2000) Thought experiments in science education: potential and current realisation. Int J Sci Educ 22(3):265–283

Gilbert JK, Boulter CJ, Rutherford M (1998) Models in explanations, Part 1: Horses for courses? Int J Sci Educ 20(1):83–97

Gilbert JK, Justi R, Queiroz AS (2010) The use of a model of modelling to develop visualization during the learning of ionic bonding. In: Taşar MF, Çakmakcı G (eds) Contemporary science education research: international perspectives. Pegem Akademi, Ankara, pp 43–51

Gobert JD, Buckley BC (2000) Introduction to model-based teaching and learning in science education. Int J Sci Educ 22(9):891–894

Jiménez-Aleixandre MP (2008) Designing argumentation learning environments. In: Erduran S, Jiménez-Aleixandre MP (eds) Argumentation in science education: perspectives from classroom-based research. Springer, Dordrecht, pp 91–115

Jiménez-Aleixandre MP, Erduran S (2008) Argumentation in science education: an overview. In: Erduran S, Jiménez-Aleixandre MP (eds) Argumentation in science education – perspectives from classroom-based research. Springer, Dordrecht, pp 3–27

Jiménez-Aleixandre MP, Pereiro Muñoz C (2002) Knowledge producers or knowledge consumers? Argumentation and decision making about environmental management. Int J Sci Educ 24(11):1171–1190

Jong J-P, Chiu M-H, Chung S-L (2015) The use of modeling-based text to improve students' modeling competencies. Sci Educ 99(5):986–1018

Justi R, Gilbert JK (2002) Modelling, teachers' views on the nature of modelling, implications for the education of modellers. Int J Sci Educ 24(4):369–387

Kuhn T (2012) The structure of scientific revolutions, 50th edn. University of Chicago Press, Chicago

Lederman N, Lederman J (2014) Research on teaching and learning of nature of science. In: Lederman NG, Abell SK (eds) Handbook of research on science education, vol 2. Routledge, New York, pp 600–620

Lin J-W (2014) Elementary school teachers' knowledge of model functions and modelling processes: a comparison of science and non-science majors. Int J Sci Math Educ 12(6):1197–1220

Lin J-W, Chiu MH (2010) The mismatch between students' mental models of acids/bases and their sources and their teacher's anticipations thereof. Int J Sci Educ 32(12):1617–1646

Lin H-S, Gilbert JK, Lien C-J (eds) (2016) Science education research and practice in Est Asia: trends and perspectives. Higher Education Publishibg Co, Taipei

Liu C-J, Hou I-L, Chiu H-L, Treagust DF (2014) An exploration of secondary students' mental states when learning about acids and bases. Res Sci Educ 44:133–154

Maia PF, Justi R (2009) Learning of chemical equilibrium through modelling-based teaching. Int J Sci Educ 31(5):603–630

Mendonça PCC, Justi R (2011) Contributions of the model of modelling diagram to the learning of ionic bonding: analysis of a case study. Res Sci Educ 41(4):479–503

Mendonça PCC, Justi R (2013) The relationships between modelling and argumentation from the perspective of the model of modelling diagram. Int J Sci Educ 35(14):2007–2034

Morrison M, Morgan M (1999) Models as mediating instruments. In: Morgan M, Morrison M (eds) Models as mediators. Cambridge University Press, Cambridge, pp 10–37

Mortimer E, Scott P (2003) Meaning making in secondary science classrooms. Open University Press, Maidenhead

Mozzer NB, Justi R (2011) Students’ analogical reasoning when participating in modelling-based teaching activities. In: Bruguière C, Tiberghien A, Clément P (eds) Ebook proceedings of the ESERA 2011 conference – science learning and citizenship. Université de Lyon, Lyon, pp 764–769

Oh PS, Oh SJ (2011) What teachers need to know about models: an overview. Int J Sci Educ 33(8):1109–1130

Oliveira DKBS, Justi R, Mendonça PCC (2015) The use of representations and argumentative and explanatory situations. Int J Sci Educ 37(9):1402–1435

Passmore CM, Svoboda J (2012) Exploring opportunities for argumentation in modelling classrooms. Int J Sci Educ 34(10):1535–1554

Prins GT, Bulte AMW, van Driel J, Pilot A (2009) Students' involvement in authentic modelling practices as contexts in chemistry education. Res Sci Educ 39(5):681–700

Sampson V, Clarke D (2008) The impact of collaboration on the outcomes of scientific argumentation. Sci Educ 93(3):448–484

Sampson V, Grooms J, Walker JP (2011) Argument-driven inquiry as a way to help students learn how to participate in scientific argumentation and craft written arguments: an exploratory study. Sci Educ 95(2):217–257

Song J, Ogawa M, Wen ML, Mu X, Na J (2016) Current trends in science education in East Asia (1995–2014). In: Lin H-S, Gilbert JK, Lien C-J (eds) Science education research and practice in East Asia (1995–2014). Higher Education Publishing Co, Teipai, pp 131–190

Svoboda J, Passmore CM (2013) The strategies of modeling in biology education. Sci & Educ 22(1):119–142

Treagust D, Harrison A, Venville G (1998) Teaching science effectively with analogies: an approach for pre-service and inservice teacher education. J Sci Teach Educ 92(2):85–101

Van den Akker J (1998) The science curriculum: between ideals and outcomes. In: Fraser BF, Tobin KG (eds) International handbook of science education, vol 1. Kluwer, Dordrecht, pp 421–448

Windschitl M, Thompson J, Braaten M (2008) Beyond the scientific method: model-based inquiry as a new paradigm of preference for school science investigations. Sci Educ 92(5):941–967

Wu H-K (2010) Modelling a complex system: using novice-expert analysis for developing an effective technology-enhanced learning environment. Int J Sci Educ 32(2):195–219

Wu H-K, Wu P-H, Zhang W-X, Hsu Y-S (2013) Investigating college and graduate students’ multivariable reasoning in computational modelling. Sci Educ 97:337–366

Zhang B, Liu X-L, Krajcik J (2006) Expert models and modelling processes associated with a computer-modelling tool. Sci Educ 90:579–604

Chapter 3
Exploring Mechanistic Reasoning in Chemistry

Vicente Talanquer

Abstract Science educators across the world recognize the importance of developing students' ability to build arguments and explanations using scientific models. However, the type of mechanistic reasoning that we would like students to develop is challenging for many learners because it demands the simultaneous analysis of multiple factors operating at different scales. In this contribution, we summarize the major reasoning challenges that we have uncovered in our studies focused on the analysis of students' ability to use structure-property relationships to build mechanistic explanations about chemical substances and phenomena. Our investigations have revealed that students at all educational levels often rely on implicit knowledge and reasoning strategies to simplify tasks. In particular, they tend to apply quick heuristics that facilitate decision-making and intuitive schemas that simplify the construction of inferences. The three most common types of heuristics used by the participants in our studies include recognition, similarity, and one-reason decision-making. The most dominant intuitive schemas elicited by our research are an additive property schema and a centralized causality schema.

Introduction

Science education reform efforts in the past 20 years have stressed the need for students to actively engage in generating arguments and building explanations of relevant phenomena using scientific models (NRC 2007, 2011, 2013). Students' initial explanations of a process or event will likely include a variety of nonnormative ideas, some more productive than others. However, by asking students to express and discuss their ideas in public, teachers can assess student understanding, provide formative feedback, and better scaffold student learning (Windschitl et al. 2012). In this environment, a teacher's ability to notice more or less productive ways of thinking and to effectively respond to and build upon the ideas that students express strongly depends on her or his knowledge of how novice learners and

---

V. Talanquer (✉)
University of Arizona, Tucson, USA
e-mail: vicente@u.arizona.edu

J. Yeo et al. (eds.), *Science Education Research and Practice in Asia-Pacific and Beyond*, DOI 10.1007/978-981-10-5149-4_3

experts in the field reason about the systems and processes under consideration (Coffey et al. 2011; Robertson et al. 2016).

Explanations of natural phenomena generated by scientists in different disciplines tend to be mechanistic in nature (Russ et al. 2008). These mechanistic accounts invoke the existence of specific agents (e.g., atoms, molecules, cells, organs) with particular properties (e.g., mass, charge, selective permeability) that determine how different agents interact with each other and the types of processes or activities in which they participate (Machamer et al. 2000). Mechanistic explanations are highly valued in science because they can be used to describe, explain, and predict the behavior of many systems of interest. Unfortunately, research in science education has shown that students often struggle to build mechanistic accounts of natural phenomena (Bolger et al. 2012; Grotzer 2003; Talanquer 2010) and that few science teachers know how to foster, scaffold, and assess students' development in this area (Robertson et al. 2016; Russ et al. 2009).

To better support the work of chemistry teachers and students when engaging in the construction of explanations, our research group has sought to characterize major roadblocks in the elaboration of mechanistic accounts of chemical phenomena. In particular, we have focused our attention on the characterization of patterns of reasoning that affect students' ability to explain and predict physical and chemical properties of substances using chemical models of the composition and structure of their submicroscopic components. The ability to build arguments and explanations based on structure-property relationships is a core competence in chemistry, and it is thus critical for teachers to recognize the types of difficulties that students face in developing and applying this type of reasoning. The central goal of this contribution is to summarize the reasoning challenges that we have uncovered and to discuss their implications for chemistry education at the secondary school and college levels.

Expert Reasoning About Structure-Property Relationships

Chemical scientists have developed a variety of models to explain and predict the physical and chemical properties of the different substances in our surroundings. Many of these models describe the composition and structure of matter at submicroscopic scales (Taber 2013a; Talanquer 2011). It is proposed, for example, that many pure chemical compounds are composed of myriads of identical particles (e.g., molecules, ions) in constant motion and interaction. The composition and structure of these particles are assumed to be unique for each type of substance and responsible for its macroscopic properties. A considerable amount of practical and theoretical efforts are thus invested in building composition-structure-property connections.

Chemical models of submicroscopic structure are mechanistic in nature. A specific set of agents, such as electrons, atoms, ions, and molecules, are defined and used to build mechanisms that explain how and why processes of interest (e.g., phase transitions, chemical reactions) happen. Relevant agents are assumed to have certain properties that determine their behaviors. Many of these properties are implicit rather than explicit, such as electrical charge, electronegativity, polarity, and polarizability. These properties affect how an agent interacts with other agents of the same or different types. These interactions, in turn, determine how a large collection of agents may respond to changes in their environment. For example, how their spatial and speed distributions may change when energy is exchanged with the surroundings.

Many models of chemical systems assume that the properties of a macroscopic sample of a material "emerge" from the random interactions and configurations that its submicroscopic components can adopt under particular conditions (Luisi 2002). This assumption implies that observed macroscopic properties differ from the properties attributed to the individual particles that compose the system. For example, the flexibility of a plastic is not explained as resulting from the flexibility of its individual molecular components but rather as emerging from the specific arrangement of and interactions between the myriads of molecules that make up the material. Nevertheless, the nature of these arrangements and interactions may often be inferred from the composition and structure of the individual particles.

Mechanistic explanations in chemistry frequently involve shifting between different scales of description of the agents, interactions, and processes that are invoked to explain or predict a phenomenon (Gilbert and Treagust 2009; Taber 2013a; Talanquer 2011). To illustrate this point, let us look at an explanation for why oil does not dissolve in water. As we begin our explanation, we may pay attention to the atomic composition and structure of a single molecule of each substance (analysis at a molecular scale). This information can be used to infer how electronic charge is distributed between the different atoms that comprise each molecule (analysis at an atomic scale) and thus make claims about molecular polarity and polarizability (analysis at the molecular scale). These inferred properties support predictions about the nature and relative strength of the intermolecular forces between different types of particles and allow us to evaluate whether the mixed or the unmixed states are more likely to be observed. However, the likelihood of mixing also depends on the extent to which the process increases or decreases the number of configurations that the collection of interacting particles can adopt (analysis at the multi-particle scale). In general, the construction of sound mechanistic explanations of chemical phenomena demands the analysis of interactions and processes occurring at the atomic, molecular, and multi-particle scales. We can surmise that such explanatory effort may be a daunting task for many learners, as well as a major instructional challenge for the teachers who seek to engage students in that type of reasoning.

Novice Reasoning About Structure-Property Relationships

Answers to questions involving structure-property relationships demand the identification of the various compositional and structural factors that are relevant in explaining or predicting the macroscopic properties of the substances of interest. In general, decisions need to be made about what factors to consider, and inferences should be built about the relative effects of these factors on the properties of interest. Our research studies have revealed that many students struggle with these types of multivariate problems in chemistry. Rather than applying explicit mechanistic reasoning based on scientific models, they often rely on implicit knowledge and reasoning strategies to simplify the tasks. In particular, they tend to apply quick heuristics that facilitate decision-making and intuitive schemas that simplify the construction of inferences. Major research findings in each of these two areas are summarized in the following paragraphs.

Heuristic Strategies

Research on human reasoning in social contexts has shown that people often rely on fast and frugal heuristics to make judgments and decisions (Kahneman 2011). These heuristics are tacit strategies for searching, selecting, and acting on relevant cues when making decisions. They can be thought of as implicit rules of thumb for quickly making choices under conditions of limited time, knowledge, or motivation to complete a task (Todd and Gigerenzer 2000). For example, we often rely on a "recognition" heuristic when buying a new product sold by different brands: we tend to choose the brand that we recognize despite the lack of information about the actual quality of all choices. The use of heuristic strategies often leads to reasonable decisions in diverse contexts, but it is also responsible for a variety of biases in judgment and decision-making. Although different heuristic strategies have been identified, they seem to share a similar cognitive mechanism (Morewedge and Kahneman 2010).

When asked to make a choice given limited time and information, the human mind tends to look for explicit and implicit differences between existing options, processing first those features that are more salient to an individual (Oppenheimer 2008). The most salient features are likely to include explicit characteristics, such as the relative size of objects, or familiar characteristics, such as the name of a known brand. During this search, our mind seeks to associate the noticed salient feature with the actual quality under evaluation. For example, in deciding whether Peter or John is more generous, our mind may first process the fact that Peter invited us for lunch 2 days ago. This action is likely to be associated with generosity in our mind, biasing our choice toward Peter. These cognitive processes unconsciously lead us to substitute a difficult question (e.g., who is more generous?) by a simpler one (e.g., who invited us to lunch recently?). In general, the choices that people make are strongly influenced by the features that are most salient to them in a given context and by the implicit associations made in their minds (Kahneman 2011).

We have been interested in exploring the extent to which chemistry students rely on heuristic reasoning rather than on mechanistic reasoning when engaged in making judgments, decisions, and predictions in chemical contexts (Talanquer 2014). Through questionnaires and individual interviews with college students who have completed general chemistry and organic chemistry courses at our university, we have investigated how they make decisions about the relative values of physical and chemical properties of different sets of substances. For example, how they decide which chemical compound in a set will have the highest melting point, be most soluble in water, or be the strongest acid (Maeyer and Talanquer 2010; McClary and Talanquer 2011). We have also analyzed how they decide which chemical reaction in a group will be most thermodynamically favored (Maeyer and Talanquer 2013). Making these choices demands the application of relevant structure-property relationships as well as properly weighing the effects of different variables. Our work has revealed that a large proportion of college students consistently rely on heuristic reasoning to make these types of chemical decisions, eluding the application of mechanistic reasoning.

The three most common types of heuristics used by the participants in our studies include recognition, similarity, and one-reason decision-making. When using *recognition*, students seem to apply the following rule when comparing and ranking chemical substances or processes: "If an option is recognized that exhibits the property under evaluation, place this option at the top or bottom of the ranking" (Goldstein and Gigerenzer 2002). For example, when comparing the acid strength of HCl, HBr, and HI, a significant number of general chemistry students selected HCl as the strongest acid simply because they recognized it as a strong acid of common use in the laboratory. Similarly, many students chose NaCl as the most soluble substance in a set also including NaBr and NaI based on their familiarity with the solubility of common salt. In our studies, "recognition" often provided a quick anchor for students to begin the ranking process reducing the likelihood of invoking structure-property relationships to justify decisions (Maeyer and Talanquer 2010).

Similarity is another heuristic often used by students to make and justify their choices. When applying this reasoning strategy, individuals identify similarities in explicit features of the substances or processes under analysis and use these similarities to guide their choices (Read and Grushka-Cockayne 2011). For example, in comparing the acid strength of HCl, HBr, and H_2S, students using this heuristic may judge HBr to be stronger than H_2S simply based on the similarity between the chemical formulas of the HBr and HCl (a substance that many students recognize as a strong acid). The use of similarity offers a shortcut for the more cognitive demanding task of identifying and weighing the effects of the different structural factors that affect acid strength (e.g., bond strength in the acid molecules, charge density and polarizability of the conjugate base molecules, etc.). Students who actually embark in this type of structural analysis frequently end up simplifying their reasoning by selecting a single variable on which to base their decision. Students who apply this *one-reason decision-making* heuristic (Gigerenzer and Gaissmaier 2011) search for a cue (one at a time) that can be used to differentiate between options (e.g., bromine is more electronegative than sulfur, H_2S has two hydrogen atoms) and then select the option with the highest or lowest cue value (e.g., HBr is a stronger acid than H_2S because the Br atom is more electronegative than the sulfur atom, H_2S is a stronger acid than HBr because it has more hydrogen atoms).

Heuristic reasoning is guided by the cues that individuals more easily identify when facing a problem. Thus, their reasoning may not be consistent across tasks as different types of features may be more salient in different contexts. What characteristics of the substances or processes represented in a chemistry task are most salient to students depend on their prior knowledge and experiences, which influence the assumptions they make about the nature and properties of the objects and events under consideration. Let us analyze some of the most common assumptions guiding novice chemistry students' reasoning.

Intuitive Schemas

Through constant interaction with the natural and social worlds, our mind develops implicit assumptions about the properties and behaviors of different entities and processes taking place in our surroundings (Chi 2008; diSessa 1993; Vosniadou et al. 2008). We assume, for example, that solid objects will always move in continuous trajectories and will not suddenly disappear into thin air (Spelke and Kinzler 2007). These types of assumptions guide the explanations and predictions we make when confronted with familiar and unfamiliar problems or situations. Imagine you were sitting in a chemistry class learning for the first time about the electrons and protons that make up an atom. In this situation, it is likely that your mind will tacitly categorize these subatomic entities as tiny solid particles and attribute to them the set of properties we associate with solid objects (e.g., moving coherently through space, persisting over time, being impenetrable). These implicit assumptions will help you make sense of what you are learning about entities you have never seen or interacted with before but may constrain your thinking when learning about, for example, the dual particle-wave nature of matter.

A significant part of our research has been focused on identifying and characterizing the implicit assumptions that novice chemistry students make when thinking about chemical systems and phenomena (Talanquer 2006, 2009, 2013a). Our findings suggest that some of these assumptions are tightly interrelated and can be conceived as intuitive schemas that guide but also constrain the explanations and predictions that students make (Talanquer 2015). Other authors in the conceptual change literature have identified these types of intuitive cognitive elements and discussed their critical role in the construction of knowledge. They have referred to them as framework presuppositions (Vosniadou et al. 2008), core hypotheses and ontological beliefs (Chi 2008), and core knowledge (Spelke and Kinzler 2007). These intuitive cognitive elements are frequently the source of alternative conceptions about specific systems or phenomena (Brown 2014; Chi et al. 2011; Coley and Tanner 2015; Taber and García-Franco 2010; Talanquer 2006), but they can serve as productive resources in the development of scientific understandings (Wiser and Smith 2016).

The intuitive schemas that seem to guide novice students' reasoning in chemistry often differ from the normative schemas used by experts to build structure-property relationships and seem to be resistant to change with training in the discipline. Results from our investigations indicate that the application of these schemas may depend on the nature of the question or problem faced by the students. Two of the most pervasive schemas elicited by our studies are the “additive property” schema and the “centralized causality” schema described below. These schemas have a strong influence on how students think about structure-property relationships.

Additive Property Schema This intuitive schema seems to guide students’ inferences about the properties of substances based on available information about their chemical composition and structure. The core interrelated assumptions that characterize this schema may be expressed as (Taber and Garcia-Franco 2010; Talanquer 2008, 2015):

(a) Chemical substances can be thought of as homogeneous aggregates or mixtures of diverse components (e.g., atoms, elements, ions, molecules, chemical bonds).
(b) Each component has inherent properties that are not affected by the presence of other components.
(c) The properties of each component are the same at all scales, from the macro to the submicroscopic scale.
(d) The properties of the substance result from the weighted average of the properties of all its components.

This “additive property” schema manifests in diverse ways when students engage in thinking about the relationship between chemical compositional and structural features and observable properties. For example, when college chemistry students were asked about the likely color, flavor, or smell of the product of a chemical reaction, the majority of them selected an answer consistent with the assumption of simple combination of properties of the reactants (e.g., the reaction between a blue reactant and a yellow reactant produces a green product) (Talanquer 2008). This response was common not only among novice college students but also among students who had completed 1 and 2 years of chemistry courses at our university (Talanquer 2013a). Similarly, these types of students inferred that a substance like silver chloride (AgCl) was likely to be shiny and malleable due to its silver content and that methanol (CH_4O) or ethanol (C_2H_6O) was more combustible than methane (CH_4) because their molecules contained oxygen, a substance they assumed to be flammable (Banks et al. 2015; Cullipher et al. 2015).

When learners apply an “additive property” schema, they think of the components of a chemical system as noninteractive parts with fixed properties. For example, they think of molecules as composite static objects that require energy to be assembled, and the larger the number of atoms in the molecule, the larger the amount of energy that needs to be invested to synthesize it (Maeyer and Talanquer 2013). When making judgments about the chemical reactivity of a molecular entity, students who apply this intuitive schema tend to pay attention to the number of atoms of a certain type which are seen as responsible for particular behaviors. For example, the more electronegative atoms are present in a molecule, the more reactive the molecule will be, or the more acidic protons a molecule has, the stronger acid it will be. The “additive property” schema supports reasoning based on a one-reason decision-making heuristic, where a single property of a component is used as cue to make inferences of the form “more A-more B” (Cooper et al. 2013; Stavy and Tirosh 2000).

The “additive property” schema applied by novice learners is substantially different from the “emergent property” schema held by expert chemists who think of atoms, molecules, and chemical substances as dynamic collection of interacting particles, with properties that emerge from such interactions. When using an emergent property schema to reason about a chemical system, inferences about properties are built based on the analysis of potential interaction between components rather than on the mere identification of the types of constituents and the quantification of their amounts. Research in chemistry education suggests that the shift from an “additive property” to an “emergent property” schema is not easy for many learners. We have found students at different educational levels expressing ideas that suggest they hold an additive property schema when reasoning about chemical substances and processes (Banks et al. 2015; Cullipher et al. 2015; Talanquer 2008). However, more advanced students tend to think of some properties in additive ways while thinking about other properties using an emergent property schema. For example, they may explain the difference in boiling points between CH_4 and CH_4O based on the relative strength of intermolecular interactions between molecules of these compounds, while attributing higher combustibility to CH_4O simply based on the presence of an extra oxygen atom in the molecules of this compound. These results suggest that the shift from one schema to the other is gradual and property dependent.

Centralized Causality Schema Students’ reasoning about why and how physical and chemical processes happen based on compositional and structural cues is often guided by an intuitive schema based on the following interrelated implicit assumptions (Grotzer 2003; Resnick 1996; Talanquer 2006, 2013b):

(a) Processes are caused or driven by an active agent that can either orchestrate events or create conditions to enable them. This active agent acts on one or more passive agents.
(b) Processes are conceived as a linear chain of sequential events resulting from the action of one or more protagonists.
(c) The active agent tends to act purposefully, seeking to achieve some goal that will allow the system adopt a more desirable state.

This way of thinking has been elicited in different contexts, from asking students to make sense of bonding patterns in chemical compounds to asking them to explain why certain compounds react with one another. For example, chemistry students commonly think that ionic compounds are formed in a process in which some active atoms take away electrons from other more passive atoms that willingly donate their electrons. Such electron exchange is judged to occur because each type of atom “wants” to acquire a full valence electron shell (Taber 1998, 2013b; Talanquer 2013b). In our investigations of how students think about why and how different types of chemical reactions happen, the most common way of thinking expressed by undergraduate and graduate chemistry students rested on the assumption that substances react with each other in order to become more stable (Yan and Talanquer 2015). Highly reactive substances were often seen as the initiators of chemical processes that would take them to lower energy states. Within this schema, students consider that molecules of an acid donate a proton to molecules of a base in order to become more stable, and oxidizing agents take electrons from reducing agents for the same purpose. Stability is often associated with reduced energy, and thus a system's desire to reduce its energy is judged as the major driver for chemical change (Weinrich and Talanquer 2015).

As was the case with the "additive property" schema, the results of our investigations reveal that the application of a "centralized causality" schema is more common when thinking about some types of systems than others. For example, undergraduate and graduate chemistry students are more likely to apply this schema when thinking about reactions in which two substances combine to form a single product (combination reactions) than when analyzing processes in which two substances participate in a double displacement reaction. In this latter case, students are more likely to invoke a mechanism based on attraction and repulsion of charged particles to explain the process (Yan and Talanquer 2015). This result suggests that the intuitive "centralized causality" schema loses strength as explanatory tool on a case-by-case basis as students assimilate alternative mechanisms to explain chemical processes.

One can expect that students will struggle to develop more normative ideas about why and how physical and chemical processes happen using compositional and structural cues. Mechanistic explanations in chemistry typically involve the analyses of two of more processes occurring simultaneously across the system. Some of these processes may be conceptualized as opposite to each other (e.g., evaporation versus condensation, forward reaction versus backward reaction). The net outcome of these processes is determined by internal and external constraints that affect the relative probability of different random events. Observable patterns at the macroscopic level emerge from the continuous and dynamic random interaction of particles at the submicroscopic level. These interactions have equal status, with no recognizable "leaders" or "enablers." The required analyses are multivariate and multiscale in nature and thus demand high cognitive effort. Students' minds tend to simplify this task by focusing on a single agent and a single process, thinking at a single scale, and attributing preferentiality to probable outcomes.

Conclusions and Implications

The type of mechanistic reasoning that we would like our students to apply in chemistry classrooms is challenging for many learners because it demands the analysis of multiple variables and simultaneous processes. Additionally, it requires that students build connections between agents, properties, and processes defined at different scales (Taber 2013a; Talanquer 2011). These types of mechanistic explanations are quite different from the types of explanations we commonly build in our daily lives to make sense of the differences in properties and behaviors of the diverse entities and events happening in our surroundings. The human mind often develops implicit reasoning strategies to facilitate judgment and decision-making (Kahneman 2011), as well as tacit assumptions about the nature of things that guide the construction of inferences (Spelke and Kinzler 2007; Talmy 1988). These same heuristics and assumptions seem to guide students' thinking in the classroom and may constrain the application of more sophisticated mechanistic reasoning.

The results of our research suggest that novice learners tend to conceive chemical substances as composite objects and explain their properties and behaviors in terms of the inherent properties and behaviors of their individual components. This is not very different from how we make sense of the differences we observe in objects in our surroundings (Cimpian and Salomon 2014). We assume, for example, that the different colors in the wings of butterflies are due to the presence of different colored pigments, rather than considering that those colors actually emerge from interactions between wing materials and solar light. Our thinking about the changes that take place around us is also similar to that expressed by students when reasoning about physical and chemical changes in the classroom. We tend to think of larger, stronger, and faster objects as having more agency than smaller, weaker, and slower ones (Talmy 1988). We also tend to attribute intentionality to processes when there is none, like when we assume that plants turn toward the sun to get more light or that ants communicate with each other to gather their food (Kelemen and Rosset 2009). The assumptions that we make affect the features of a system or phenomenon to which we pay attention, biasing our judgments and decisions. Heuristic reasoning is as pervasive in our daily lives as it is in the classroom.

Our studies indicate that students develop the ability to use normative mechanistic reasoning to think about chemical systems and phenomena, but this ability seems to develop slowly and in pieces (Weinrich and Talanquer 2015; Yan and Talanquer 2015). This is, students learn to think in normative mechanistic ways about some specific processes while applying intuitive schemas to reason about others. This fragmentation may be due in part to our traditional approaches to teaching chemistry which focus more on acquisition of factual knowledge than on the development of productive ways of thinking in the discipline. Students tend to be confronted with mechanistic reasoning in isolated situations (e.g., explaining why a substance dissolves in water or why a chemical reaction reaches equilibrium), but there is no systematic effort to help them develop mechanistic frameworks that can be applied across different types of phenomena.

Traditional chemistry courses are organized as a sequence of topics (e.g., atomic structure, chemical bonding, chemical reactions) rather than around fundamental ways of reasoning in the domain. Teachers tend to emphasize the acquisition of descriptive knowledge and basic problem-solving skills. In these traditional environments, students learn to, for example, balance chemical equations, calculate amounts of substances, draw Lewis structures, and assign oxidation states. There are far fewer opportunities for students to engage in building arguments and explanations to make sense of properties and phenomena in relevant situations (Sevian and Talanquer 2014; Talanquer and Pollard 2010). Even when they do, few teachers are prepared to press students to generate mechanistic accounts, support learners in these efforts, and create activities that help them build generalizable ways of thinking that can be applied across different contexts (Russ et al. 2009; Robertson et al. 2016).

There is evidence to support the claim that students can engage in sophisticated mechanistic reasoning when given opportunities to do so in scaffolded learning environments. In these types of classrooms, students are confronted with authentic problems and asked to build explanations or design solutions using models (Windschitl et al. 2008, 2012). Teachers implement activities that elicit students' ideas and make their thinking public. Shared ideas can then be analyzed and challenged if necessary. Many students often express productive ways of reasoning that can be used to build more normative understandings (Wiser and Smith 2016). Comparing and contrasting different ways of explaining a system or phenomenon helps students identify the scope and limitations of different types of reasoning (Chi et al. 2011). Engaging students in collaborative construction of ideas has been shown to be highly successful in fostering the development of meaningful understandings (NRC 2005; Chi and Wylie 2014).

Changing the teaching approach, however, is only a part of what is needed to strengthen students' ability to engage in normative mechanistic reasoning. Chemistry educators and chemistry education researchers also need to more carefully reflect on the type of mechanistic reasoning that would be most productive for students to develop. There are major ways of explaining and inferring chemical properties and phenomena based on structure-property relationships that need to be made more explicit to both teachers and students (Talanquer 2015). Chemistry curricula could be modified to use these fundamental ways of thinking as central axes in the organization of the core ideas discussed and the major activities implemented in the classroom. A focus on fundamental mechanisms would help students better understand how some basic ideas in chemistry can be used to make sense of the properties of many diverse substances and a wide range of phenomena.

Acknowledgments The author wishes to acknowledge the funding source, US NSF award DRL-1221494, that provided support for his research activities.

References

Banks G, Clinchot M, Cullipher S, Huie R, Lambertz J, Lewis R, Ngai C, Sevian H, Szteinberg G, Talanquer V, Weinrich M (2015) Uncovering chemical thinking in students' decision making: a fuel-choice scenario. J Chem Educ 92:1610–1618

Bolger M, Kobiela M, Weinberg PJ, Lehrer R (2012) Children's mechanistic reasoning. Cogn Instr 30(2):170–206

Brown DE (2014) Students' conceptions as dynamically emergent structures. Sci & Educ 23:1463–1483

Chi MTH (2008) Three kinds of conceptual change: belief revision, mental model transformation, and ontological shift. In: Vosniadou S (ed) International handbook of research on conceptual change. Routledge, New York, pp 61–82

Chi MTH, Wylie R (2014) The ICAP framework: linking cognitive engagement to active learning outcomes. Educ Psychol 49(4):219–243

Chi MTH, Roscoe RD, Slotta JD, Roy M, Chase CC (2011) Misconceived causal explanations for emergent processes. Cogn Sci 36(1):1–61

Cimpian A, Salomon E (2014) The inherence heuristic: an intuitive means of making sense of the world. Behav Brain Sci 37:461–527

Coffey JE, Hammer D, Levin DM, Grant T (2011) The missing disciplinary substance of formative assessment. J Res Sci Teach 48(10):1109–1136

Coley JD, Tanner K (2015) Relations between intuitive biological thinking and biological misconceptions in biology majors and nonmajors. CBE Life Sci Educ 14:1–19

Cooper MM, Corley LH, Underwood SM (2013) An investigation of college chemistry students' understanding of structure–property relationships. J Res Sci Teach 50:699–721

Cullipher S, Sevian H, Talanquer V (2015) Reasoning about benefits, costs, and risks of chemical substances: mapping different levels of sophistication. Chem Educ Res Pract 16:377–392

diSessa AA (1993) Toward an epistemology of physics. Cogn Instr 10(2&3):105–225

Gigerenzer G, Gaissmaier W (2011) Heuristic decision making. Annu Rev Psychol 62:451–482

Gilbert JK, Treagust DF (eds) (2009) Multiple representations in chemical education. Springer, Dordrecht

Goldstein DG, Gigerenzer G (2002) Models of ecological rationality: the recognition heuristic. Psychol Rev 109:75–90

Grotzer T (2003) Learning to understand the forms of causality implicit in scientifically accepted explanations. Stud Sci Educ 39:1–74

Kahneman D (2011) Thinking, fast and slow. Farrar, Straus and Giroux, New York

Kelemen D, Rosset E (2009) The human function compunction: teleological explanation in adults. Cognition 111:138–143

Luisi PL (2002) Emergence in chemistry: chemistry as the embodiment of emergence. Found Chem 4:183–200

Machamer P, Darden D, Craver CF (2000) Thinking about mechanisms. Philos Sci 67:1–25

Maeyer J, Talanquer V (2010) The role of intuitive heuristics in students' thinking: ranking chemical substances. Sci Educ 94:963–984

Maeyer J, Talanquer V (2013) Making predictions about chemical reactivity: assumptions and heuristics. J Res Sci Teach 50:748–767

McClary L, Talanquer V (2011) Heuristic reasoning in chemistry: making decisions about acid strength. Int J Sci Educ 3:1433–1454

Morewedge CK, Kahneman D (2010) Associative processes in intuitive judgment. Trends Cogn Sci 14:435–440

National Research Council (NRC) (2005) How students learn: history, mathematics, and science in the classroom. National Academies Press, Washington, DC

National Research Council (NRC) (2007) Taking science to school: learning and teaching science in grades K-8. National Academies Press, Washington, DC

National Research Council (NRC) (2011) A framework for K-12 science education: practices, crosscutting concepts, and core ideas. Committee on a conceptual framework for new K-12 science education standards. National Academies Press, Washington, DC

National Research Council (NRC) (2013) The next generation science standards. National Academies Press, Washington, DC

Oppenheimer DM (2008) The secret life of fluency. Trends Cogn Sci 12:237–241

Read D, Grushka-Cockayne Y (2011) The similarity heuristic. J Behav Decis Mak 24:23–46

Resnick M (1996) Beyond the centralized mindset. J Learn Sci 5(1):1–22

Robertson AM, Scherr R, Hammer D (eds) (2016) Responsive teaching in science and mathematics. Taylor & Francis, New York

Russ RS, Scherr RE, Hammer D, Mikeska J (2008) Recognizing mechanistic reasoning in student scientific inquiry: a framework for discourse analysis developed from philosophy of science. Sci Educ 92(3):499–524

Russ RS, Coffey JE, Hammer D, Hutchison P (2009) Making classroom assessment more accountable to scientific reasoning: a case for attending to mechanistic thinking. Sci Educ 93(5):875–891

Sevian H, Talanquer V (2014) Rethinking chemistry: a learning progression on chemical thinking. Chem Educ Res Pract 15(1):10–23

Spelke ES, Kinzler KD (2007) Core knowledge. Dev Sci 10(1):89–96

Stavy R, Tirosh D (2000) How students (mis-)understand science and mathematics: intuitive rules. Teachers College Press, New York

Taber KS (1998) An alternative conceptual framework from chemistry education. Int J Sci Educ 20:597–608

Taber KS (2013a) Revisiting the chemistry triplet: drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. Chem Educ Res Pract 14:156–168

Taber KS (2013b) A common core to chemical conceptions: learners' conceptions of chemical stability, change and bonding. In: Tsaparlis G, Sevian H (eds) Concepts of matter in science education. Springer, Dordrecht, pp 391–418

Taber KS, García-Franco A (2010) Learning processes in chemistry: drawing upon cognitive resources to learn about the particulate structure of matter. J Learn Sci 19(1):99–142

Talanquer V (2006) Common sense chemistry: a model for understanding students' alternative conceptions. J Chem Educ 83(5):811–816

Talanquer V (2008) Students' predictions about the sensory properties of chemical compounds: additive versus emergent frameworks. Sci Educ 92(1):96–114

Talanquer V (2009) On cognitive constraints and learning progressions: the case of structure of matter. Int J Sci Educ 31(15):2123–2136

Talanquer V (2010) Exploring dominant types of explanations built by general chemistry students. Int J Sci Educ 32(18):2393–2412

Talanquer V (2011) Macro, submicro, and symbolic: the many faces of the chemistry "triplet". Int J Sci Educ 33(2):179–195

Talanquer V (2013a) How do students reason about chemical substances and reactions? In: Tsaparlis G, Sevian H (eds) Concepts of matter in science education. Springer, Dordrecht, pp 331–346

Talanquer V (2013b) When atoms want. J Chem Educ 90:1419–1424

Talanquer V (2014) Chemistry education: ten heuristics to tame. J Chem Educ 91:1091–1097

Talanquer V (2015) Threshold concepts in chemistry: the critical role of implicit schemas. J Chem Educ 92:3–9

Talanquer V, Pollard J (2010) Let's teach how we think instead of what we know. Chem Educ Res Pract 11:74–83

Talmy L (1988) Force dynamics in language and cognition. Cogn Sci 12:49–100

Todd PM, Gigerenzer G (2000) Précis of simple heuristics that make us smart. Behav Brain Sci 23:727–780

Vosniadou S, Vamvakoussi X, Skopeliti I (2008) The framework theory approach to the problem of conceptual change. In: Vosniadou S (ed) International handbook of research on conceptual change. Routledge, New York, pp 3–34

Weinrich M, Talanquer V (2015) Mapping students' conceptual modes when thinking about chemical reactions used to make a desired product. Chem Educ Res Pract 16:561–577

Windschitl M, Thompson J, Braaten M (2008) Beyond the scientific method: model-based inquiry as a new paradigm of preference for school science investigations. Sci Educ 92:941–967

Windschitl M, Thompson J, Braaten M, Stroupe D (2012) Proposing a core set of instructional practices and tools for teachers of science. Sci Educ 96(5):878–903

Wiser M, Smith CL (2016) How is conceptual change possible? Insights from science education. In: Barner D, Baron AS (eds) Core knowledge and conceptual change. Oxford University Press, New York, pp 29–52

Yan F, Talanquer V (2015) Students' Ideas about how and why chemical reactions happen: mapping the conceptual landscape. Int J Sci Educ 37:3066

Chapter 4
Supporting Scientific Report Writing in a Chemistry Classroom

Gde Buana Sandila Putra and Kok-Sing Tang

Abstract Communication skill is one of the competency domains gaining prominence in the twenty-first century. In Singapore, developing students' literacy and communication skills has been emphasised in all subjects, including science. Despite the emphasis, science teachers have been reluctant to shift the focus from learning content knowledge to including literacy and communication skill teaching in their repertoire. Thus, literacy activities such as reading, writing, and presenting are rarely observed in science classrooms. This study explored and examined scientific report writing activity in a secondary three chemistry classroom in Singapore. A lesson series was codeveloped with a chemistry teacher to infuse literacy activities, especially scientific report writing, in the teaching of the topic of atmosphere. Video data and student-generated group reports were collected and analysed to explore how the teacher taught scientific report writing and the outcomes of the teaching as reflected by student-generated group reports. The findings from this study suggest a need for stronger emphasis on teaching writing in science classrooms.

Introduction

In today's Digital Age, information has become more accessible. Not only can anyone retrieve information easily, they can also contribute and communicate their knowledge through writing for the world to see. When information has become the new currency in the twenty-first century, it is important for people to know how they can access, comprehend, assess, and even communicate information. It is thus crucial to have good literacy and communicative skills to navigate the twenty-first century.

G.B.S. Putra (✉)
National Institute of Education, Nanyang Technological University, Singapore
e-mail: gde.putra@nie.edu.sg

K.-S. Tang
Curtin University, Perth, Australia

J. Yeo et al. (eds.), *Science Education Research and Practice in Asia-Pacific and Beyond*, DOI 10.1007/978-981-10-5149-4_4

The development of literacy and communication has gained prominence in recent years in Singapore. The English Language Institute of Singapore, an institute under Singapore's Ministry of Education, launched the Whole School Approach to Effective Communication programme to help develop effective communication and literacy practices in all subjects, including science subject (Tang et al. 2016). Despite the emphasis on developing literacy and communication skills, many science teachers seem reluctant to infuse literacy and communication skill teaching in their classes as English language class is assumed to be taking care of it.

Literacy scholars (e.g. Fang 2014; Hillman 2013; Moje 2007; Pearson et al. 2010; Shanahan and Shanahan 2008, 2012) have been examining the notion of disciplinary literacy – the ability to use the specialised language, representations, and practices of a given discipline. They highlight that each discipline requires a different set of literacy skills as each discipline has its own conventions that are valued by the members of the discipline community. Shanahan and Shanahan (2008) proposed that disciplinary literacy is a form of advanced literacy and is specific to a discipline. Thus, a general language class does not fully cater to the specific disciplinary literacy requirements of different subjects, such as science, mathematics, and history.

In line with the notion of disciplinary literacy, Fang (2005) pointed out that science cannot be done using ordinary everyday language; science has its own peculiar language and grammar to represent the complex nature of scientific endeavours (Fang 2005; Graddol et al. 2007; Halliday and Martin 1993; Lee 1978, 1983; Wellington and Osborne 2001). Thus, not only do learners of science have to learn the content knowledge of the discipline but also the peculiar language and grammar, for example, the use of precise technical vocabulary, embedded clauses, and passive voice (Lee and Spratley 2010). Knowing scientific concepts from teachers is not enough as learners of science; they have to be able to access and comprehend scientific knowledge from texts. Science evolves rapidly, and it is important for students to be able to understand its development through reading. Furthermore, they have to be able to express their scientific knowledge verbally or in written forms for reasons including writing in examinations and sharing scientific ideas among peers. However, despite its importance, the learning of the language of science usually takes a back seat in science teaching and learning.

Writing, in particular, is an important activity in science learning. It encourages students to think and organise their thought before penning it down and makes students' thinking visible. One issue often encountered in science classrooms is that students know the relevant scientific facts and concepts but they are not able to express them in written form (Lee and Fradd 1996). This is worrying because at the end of the day, students have to write in order to demonstrate their competency in the discipline. Moreover, not knowing how to pen down their thought could be taken to mean that students are not knowledgeable in science. Although this is an issue for many students, teaching how to write is rarely observed in science classrooms, let alone giving opportunity for students to write independently. In an earlier study where we examined the time spent in various literacy activities in science classrooms in Singapore, we found that writing activity was limited to mainly copying what teachers wrote on boards. Little emphasis was given to develop students' writing skill in the science discipline (Tang 2016b).

In light of the minimal attention given to teaching writing skill, we embarked on the present study to explore and examine the teaching of report writing in science classroom. The aim of the present study was to find out how report writing was taught in science classroom and the outcome of such teaching.

The Study

The present study focused on exploring and examining the teaching of scientific writing in science classroom. In particular, we focused on report writing, which is one of the four major genres of scientific writing (Wellington and Osborne 2001). The research questions that guided the study were as follows: (1) How was report writing taught in science classroom? (2) What was the outcome of the teaching in terms of student-generated group reports?

The data for this study were taken from a larger 3-year research project aimed at developing disciplinary literacy pedagogy in science classrooms in secondary schools in Singapore. The project focused on chemistry and physics and involved four teachers from two different schools. In this study, data from one chemistry class were presented.

Context

The study was situated at a secondary 3 (grade 9) chemistry classroom in an all-girls school in Singapore. The school was recruited because the school management was interested in participating in the project. There were 28 students in the classroom, taught by a female chemistry teacher Kathryn, a pseudonym, who had 8 years of teaching experience at the time the study was conducted. The study comprised a lesson series on the topic of atmosphere, designed in conjunction with the school's self-directed learning programme in which students were expected to learn a topic independently through reading at home. The lessons were designed to develop students' literacy skills, especially report writing skill. Although report writing is not emphasised nor examinable in Singapore, Kathryn considered report writing to be a useful skill to hone as it could improve her students' communication skill which is an area of focus in the school.

Lesson Design

The lesson series on the topic of atmosphere was codeveloped with Kathryn. Although it was a joint effort in planning the lessons, Kathryn made the decision as to how the learning experience was going to be. In conjunction with the self-directed learning programme, the lessons were planned to include reading articles, writing, and presenting scientific reports, to support independent learning, and at the same time to develop students' literacy skills. The lesson series took approximately four 1-hour lessons in a span of 2-week period.

The 28 students were grouped into 7 groups of 4 and tasked to conduct a mini-research on the haze issue in Singapore as a warm-up activity in the first lesson. They were expected to look for information about haze, write a short two-to-three-paragraph report on their findings, and present their reports to the class. The activity was followed by Kathryn giving tips on how to write scientific report and deconstructing a model text to highlight the features of scientific reports to the students. Each group of the students was assigned a topic out of the four topics available – global warming, depletion of the ozone layer, air pollution, and acid rain – and tasked to write a report on the assigned topic which had to be presented to the class at the end of the lesson series. To support the report writing, each group was given a set of reading materials and writing worksheets.

In the second lesson, Kathryn gave the students extra time to read the set of reading materials, discuss about the assigned topic, write the reports, and craft their presentation slides. Kathryn was present to assist the students. The students submitted their reports, and four of the groups presented their reports in the third lesson. The rest of the groups presented their reports in the fourth lesson. Kathryn wrapped up the lesson series by summarising the presentations.

Materials

Each group was given a set of reading materials which consisted of four articles on a specific topic, e.g. global warming. The articles were obtained from various reliable sources such as *National Geographic* articles, undergraduate-level articles published in university websites, government agency websites, and children science magazine articles. The choice of articles was made based on the information they contained. They were selected to be complementary to each other, e.g. one article provided the chemical equation for acid rain, while the other provided the impact of acid rain to the environment. The set of reading materials given to the students served two purposes: (1) to expose them to and provide them with samples of the genre of scientific report and (2) to provide necessary information for the students to synthesise their reports, regardless of their reading level.

Worksheets were given to support the students in synthesising their reports. The worksheets were adapted from Literacy Design's template tasks (Crawford et al.

2011) and contained a role-play scenario in which the students had to assume the role of environmental chemists who were to educate secondary school chemistry students in Singapore about one environmental issue through their report writing and presentation. Singapore secondary school chemistry students were selected to be the audience to encourage the students to include chemical equations in their reports. Four guiding questions were included in the worksheet to help the students filter relevant information from the set of reading materials. Depending on the topic, the four guiding questions were as follows: (1) What is <the topic> (e.g. global warming)? (2) How does it come about? (3) What are some of the consequences of <the topic> (e.g. global warming)? (4) How could the consequences be minimised?

Grading rubrics were also given to the students to help them structure their reports. The rubrics were organised in a way to guide the students step-by-step in organising their reports. The grading rubrics also contained language requirement.

Data Sources

The data for this study were generated from multiple sources. The lessons were video recorded, and the video data were collected for analysis. The video data included Kathryn's facilitation/lecture, discussions among the students, and presentations by the students. Written artefacts were also collected and scanned. They included initial research reports that students did in the first lesson, their worksheets, final scientific reports, and presentation slides. For this study, video data of Kathryn's facilitation and the final scientific reports will be the focus of analysis.

Analytical Framework

The video data were analysed sequentially. Important teaching repertoire was highlighted. Student-generated group reports were analysed through systemic functional linguistics and genre analysis lenses. Systemic functional linguistic lens was used to analyse the reports for its linguistic features, while genre analysis lens was used to analyse the structure of the reports.

Linguistic Features

Fang (2005) described four peculiar features of scientific writings: informational density, authoritativeness, abstraction, and technicality. Due to the nature of the chemistry topic, we focused on two of the linguistic features, informational density and authoritativeness, in the present study.

Informational density refers to the packing of information in a text – how much information a text contains. Informational density is synonymous and reflected by lexical density. Lexical density can be measured in two ways: (1) by calculating the number of lexical items per non-embedded clause (Halliday 1994) or (2) by calculating the percentage of content words over total running words (Eggins 1994). Content words include nouns, main verbs, adjective, and some adverbs; non-content words include prepositions, conjunctions, auxiliary verbs, determiners, pronouns, and some adverbs. A clause minimally consists of a subject (as expressed by noun phrase) and a predicate (as expressed by verb phrase). Excerpt 4.1 below exemplifies how the students' reports were analysed in terms of lexical density. There are 66 words in total, of which 38 are content words, and 6 non-embedded clauses in Excerpt 4.1. Thus, the lexical density of the excerpt is 6.3 content words per non-embedded clause or 57.6% of content words.

Excerpt 4.1: An Excerpt from Student-Generated Group Report Ozone 1. Clause Boundaries Are Marked with //. Content Words Are in Bold

Ozone layer is a **belt** of **naturally occurring ozone gas** that **sits fifteen** to **thirty kilometres** above **Earth**. // Its **purpose** is to **shield Earth** away from **harmful ultraviolet B radiation emitted** by the **Sun. // Ozone** is also a **highly reactive molecule**. // It **contains three oxygen atoms**. // It is **continually** being **formed** and **broken** down in **stratosphere. // Stratosphere** is the **second major layer** of the Earth's **atmosphere**.

In scientific writing, information is typically presented objectively and in assertive tone and impersonal ways (Schleppegrell 2002). Such presentation gives rise to the feature of authoritativeness. Authoritativeness is a feature that presents to readers a sense of authority – that the text contains objective, evidence-based information that is to be taken as 'facts'. Scientific texts are written without any reference to first person, to mental processes (e.g. *I think*), and to direct quotes (Chafe 1982) to remove possible subjectivity, achieving that position of authority. Attempts to engage or 'talk' to readers are also rarely seen as such attempts lessen the degree of objectivity and impersonality. In analysing student-generated group reports, instances or signs of non-authoritativeness are identified and tabulated. For example, 'if *your parents* must use the car, *ask them* to avoid it… ' has two instances of informality as underlined. Both instances attempt to interact with readers by including readers in the text (as denoted by *your parents*) and using imperative clause (as denoted by *ask them…*).

Genre Analysis

Every genre of written text has its own ‘rule’ that distinguishes one genre from another. For example, a promotional text such as sales promotion letter is easily distinguishable from an introduction section of a research article. Swales (1981, 1990) and Bhatia (1993) proposed that the distinguishability arises from the content and organisation of information at text level. The organisation of information at text level is built upon what Bhatia (1993) called rhetorical move structure. Texts are constructed through carefully thought moves or steps to achieve the intended communicative purpose. For example, promotional texts typically have seven-move structure (Bhatia 1993): (1) establishing credentials, (2) introducing the offer, (3) offering incentive, (4) enclosing documents, (5) soliciting response, (6) using pressure tactics, and (7) ending politely. Likewise, scientific texts have their own unique genres and thus have their own set of rhetorical move structures.

There are four major genres of science: report, explanation, experimental account, and exposition/argumentation (Martin and Miller 1988). The student-generated group reports fall under the report genre, specifically the descriptive report genre. Descriptive reports have a communicative purpose of informing readers about scientific phenomena, concepts, or ideas. Unlike everyday texts, descriptive reports do not have a linear temporal narrative; rather, they have multiple parts of the same phenomenon to be described separately. Below is a seven-move organisational structure that is typically suggested for writing scientific reports (e.g. Cresent Public Schools n.d.; Monash University 2007). Using this organisational structure, student-generated group reports were analysed for their rhetorical move structure.

Stage	Rhetorical move	
Introduction	Move 1	Introducing the main phenomenon
	Move 2	Giving necessary background information
Body	Move 3	Introducing one part of the phenomenon
	Move 4	Elaborating the part
Conclusion	Move 5	Summarising the key points
	Move 6	Stating the conclusion
Reference	Move 7	Listing references

Move 1 is identified by locating the key words or question that encompasses and drives the flow of the report. Move 2 is identified when relevant background information such as definition, examples, or brief history is presented. Move 3 is typically identified by looking at the topic sentence of the body paragraph. However, it has to be relevant to and constitute the central question/phenomenon being reported. Move 4 is identified when sentences after the topic sentence answer the ‘so what?’, ‘how?’, or ‘why?’. Move 5 is identified by looking at the repetition of key points in the body paragraphs. Move 6 concludes the article by stating the main idea of the article, or the moral of the article. Move 7 is simply citing the references used in writing the article. Below is an example of how the move structure was identified in a student-generated group report.

Doomsday is approaching. *[Introduction]*
[Move 1] Well, we don't know for sure, but there is certainly global warming, which all the more confirms this statement *[Move 1]*. *[Move 2]* What is global warming? It is the slow and steady rise in the overall temperature of the earth's atmosphere mainly due to the greenhouse effect caused by increased levels of carbon dioxide, CFCs, and other pollutants. *[Move 2]*

…

What are the causes of Global Warming? *[Body]*
[Move 3] Human beings have caused the greenhouse effect, by increasing the carbon dioxide (CO_2) concentration in the atmosphere by about 30%. *[Move 3] to [Move 4]* This increase in CO_2 concentration contributes to global warming by increasing temperatures. This is because heat energy from the earth, or infrared radiation is trapped by CO_2 molecules. Thus heat energy is retained in the earth's atmosphere by CO_2 gas, causing a rise in temperature of the earth. *[Move 4]*

…

Conclusion *[Conclusion]*
[Move 5] In conclusion, global warming is a serious matter. We have to take really quick action on this matter, or our whole planet will be in danger. Humans can lose homes, food and possible even their lives due to the extreme climate changes. We should implement measures such as the three 'R's and find new ways to produce electricity *[Move 5]*. *[Move 6]* Whether doomsday comes or not, the consequences of global warming are very real and are happening presently. The ultimate choice on whether to act on this problem lies with us. *[Move 6]*

[Missing Move 7]

Findings and Analyses

Teaching Scientific Report Writing

The teaching of scientific report writing was done by, first and foremost, providing opportunity for the students to write one. If students were only lectured on how to write without providing an opportunity to apply the newly learnt skill, learning would not occur. Kathryn provided two opportunities for her students to attempt writing scientific reports. The first opportunity was given without any writing support at the start of the lesson to gauge the students' report writing skill. In the first attempt, most of the groups of the students wrote in bulleted form and were lacking organisation in their reports. Hence, prior to giving out the second writing assignment to the students, Kathryn gave a few pointers that the students need to know to be able to write a good scientific article:

> So what are some of the writing tips? Number 1. When I start to write an article, I must make sure that it is **clear and concise**… make sure your ideas are **well organised**…you should **know your audience**…, and **adjust your language accordingly**. Okay? **Use headings to organise your article systematically**…**use scientific or technical terms**, you must **understand the word that you use…** use **other scientific convention** such as **chemical equations**, or **tables** to help you **present your article more scientifically.** These are **essence**… **use passive voice whenever possible** to create **objectivity**…**use appropriate tenses**… including the **references** towards the end of your article, alright?

There were a few things that Kathryn emphasised: (1) to write clearly and concisely, (2) to be organised by using headings, (3) to use appropriate language, (4) to use scientific terms and conventions, and (5) to include references, but there was no direct reference made to the special linguistic features of scientific texts. Although knowing the linguistic features of scientific report is important, the teaching of these linguistic features may not be practical. Direct mentioning about informational density, authoritativeness, technicality, and abstraction may do little in helping students to write, or it may confuse the students. Instead, Kathryn taught ways to write that led to having linguistic features of scientific writing – something that the students could act upon immediately. For instance, to achieve conciseness, students need to pack their ideas into a few words which will result in lexically or informationally dense reports. Using appropriate language such as passive voice helps to create authoritative tone in their reports as students can distance themselves from readers. Technicality and abstraction are also achieved when students use scientific terms and conventions in their reports and also when they write concisely (Fang and Wang 2011).

Kathryn further supported her students by modelling the report writing. She took a sample report, projected it onto a screen, and deconstructed the report by highlighting the relevant features to show her students how the writing tips she gave them could come into realisation:

> If you just **take a few minutes to just take a look at this article on the flue gas desulfurisation**. So the first thing, that is important, is to make sure that it's concise, there is a heading… **you notice that apart from the main heading, I also have subheadings**. Next, in your scientific article, you're supposed to use scientific or technical terms such as chemical equations, or tables to help you to present your articles clearly. So, instead of saying, this and this will react to give you this and this, **I might as well use it in terms of an equation**... Use table or diagrams or pictures, if there is any. So for example if I want to show the entire process of a flue gas desulfurisation, **the best way to show a process is through diagram, or flowchart**.

In the above excerpt, Kathryn pointed out to her students some of the points that she made earlier. She showed them the headings and subheadings that help organise the sample report. She also highlighted that lengthy description of a reaction could be replaced by chemical equation – a signature of chemistry texts – to compress information into a more meaningful representation. The use of diagrams or flowcharts was also pointed out to be the best way to show a process.

Kathryn continued by showing her students the process of writing the article. She showed them how she could get all the information to write the sample report. She showed them her reading materials, of which the relevant points were already highlighted, and transferred the points into the writing worksheet to organise the points to form the skeleton of the reports. However, due to time constraint, Kathryn had to stop at that point. She gave out copies of the sample report to her students as a reference and writing rubrics that could help them refine their reports. The teaching of the move structure was left to the student to learn independently from the rubrics given. Kathryn continued to facilitate the writing process in the subsequent lesson by giving comments and attend to the students' questions pertaining to the reports. There was, however, no additional opportunity for the students to try their hands on applying the writing tips prior to the final report writing assignment.

Student-Generated Scientific Reports

Seven student-generated group reports were analysed for informational density and instances of non-authoritativeness. The table below summarises the result of the analysis. The rhetorical move structure was also analysed, and the moves identified in the reports were tabulated below.

Report topic	Non-authoritativeness	Lexical density (content word/ clause)	Lexical density (%)	Rhetorical move present
Ozone 1	0	7.2	48.3	2,3,4
Acid rain 1	1	7.8	52.3	1,2,3,4
Global warming 1	12	7.4	53.5	1,2,4,5,6,7
Air pollution	7	8.0	55.9	1,2,3,4
Acid rain 2	10	5.3	46.6	1,2,3,4
Global warming	10	8.7	52.8	2,3,4
Ozone 2	17	7.2	48.8	1,2,3,4,5,6
Average	**8.1**	**7.4**	**51.2**	–

The analysis of the reports shows that there are instances of non-authoritativeness in the reports, with an average of 8.1 instances. Only two groups of students (Ozone 1 and Acid rain 1) managed to maintain the feature of authoritativeness throughout their reports as reflected by the near-absence of non-authoritative instances. This result may suggest that the students may not be aware of the importance of maintaining an authoritative stance, thus objectivity, in writing scientific reports.

Taking an even closer look at the instances of non-authoritativeness that the students made, the non-authoritativeness arises mostly because of attempts to engage and interact with readers, rather than the use of first person reference, reference to mental process, or direct quotes. Examples of non-authoritative instances are presented below:

- How can we minimise the consequences?
- Do you know what the causes of air pollution are?
- As individuals, we can help prevent acid rain by conserving energy.
- If your parents must use the car, ask them to avoid using it.

The use of plural first person pronoun “we” and second person pronoun “you” may suggest that the students attempted to include the readers in the conversation to explore the phenomenon being described. While the use of the pronouns may make the reports more reader-friendly and engaging, it introduces informality and subjectivity, lessening the degree of objectivity that scientific reports typically have.

The attempts made by the students to engage readers are likely due to the fact that the students also had to present their reports at the end of the lesson series verbally. Oral communication is different from written communication in terms of the audience presence. In oral communication such as presentation, the audience is present within the same space and time as the presenters and they can interact with each other immediately. Presenters, thus, tend to be required to engage the audience present in front of them. On the other hand, in written communication, there is no immediate audience who can respond to the writers immediately; thus, there is less obligation to engage readers. Therefore, it is possible when the students were writing the scientific reports, they were writing in preparation for their presentations, using the reports as their speech guides. The interactivity in the scientific reports could be their scripts to engage the audience in their presentations.

Although authoritativeness is an important feature of scientific writing, Fang (2005) reported that there is a growing trend of using informal and interactive language in science textbooks to engage readers and capture their interest. The use of such language, however, is dangerous and students need to be careful. Schleppegrell (2004) argued that if the informal and interactive language is not carefully juxtaposed with the more authoritative and objective language of science, incoherent registers can arise. This may result in distortion of the genre as the reports lose its objectivity.

In terms of lexical density, the reports written by the students had 7.4 content words per clause or 51.2% content words over the total words on average. According to Halliday (1994), in everyday speech there are two to three content words per clause, while in written language the number increases to four to six content words per clause. The number can become considerably higher in scientific texts, sometimes as high as 10–13 content words per clause. Ure (1971) suggested lexical density of greater than 40% is considered high and implies complex writing. Although the reports written by the students can be classified as complex texts, the lexical density in terms of content words per clause is not as high as typical scientific texts as suggested by Halliday (1994). However, it is still higher than spoken language and everyday written language. The result of the analysis suggests that the students are able to produce complex texts that are considerably dense in information as reflected by the lexical density.

The result of the analysis of the rhetorical move structure of the student-generated group reports suggests that the students may not have a good grasp on how to structure their reports. Only moves 2 (giving necessary background information), 3 (introducing parts of the phenomenon), and 4 (elaborating the parts) are common across the seven reports. Moves 5 (summarising key points), 6 (stating the conclusion), and 7 (listing references) are largely absent. The absence of moves 5 and 6 suggests that writing out the conclusion could be deemed as unnecessary by the students. Likewise could also be said to providing a list of references.

The absence of the 3 rhetorical moves could affect the reports in a few ways. As the phenomenon is discussed in different parts (e.g. causes of the phenomenon, effect of the phenomenon), it is imperative to put the parts together as a whole. Thus, the absence of the conclusion section may affect readers' understanding as the information presented is left in parts. Providing a list of citation is also important to convince readers that the information presented in the reports is obtained from reliable sources. Failing to provide reference may affect the reliability and the authoritativeness of the reports.

Finally, the analysis shows an interesting result. The reports that have the linguistic features of scientific texts do not have the structure. This suggests that having appropriate writing style and information organisation at the sentence level, which are responsible for the features of authoritativeness and informational density, does not translate into organisation of information at the text level as reflected by the rhetorical move structure.

Discussion

The teaching of scientific report writing was brief due to time constraint but seemed effective for the most parts as reflected by the analysis of the students' reports. Kathryn was able to point out the relevant points that allow students to write the reports effectively. What is worth noting in her lesson was the deconstruction of the sample report. In science teaching and learning, teachers tend to provide answers (e.g. explanation or description), but the answers are normally not unpacked to students. There is a missing puzzle that students have to solve as they have to figure out on their own how to arrive at the answers or the way to structure the answers. In the lessons observed, Kathryn unpacked the scientific writing by talking about how students could write the report and also working backward to show how her writing tips were realised in the sample report. This is in line with the genrist point of view. According to Hyland (2007), it is important to surface writing convention including linguistic features and organisation of information. It allows students to have the 'mould' of the reports they ought to write. Although this 'mould' method seems rigid and allows little room for creativity, it is important to remember that the students were not experienced report writers and therefore familiarising the students with the genre would be of higher priority.

However, the absence of opportunity for the students to try applying the writing tips prior to the final assignment could contribute to the ineffectiveness reflected by some missing moves and the many instances of non-authoritativeness in some of the students' reports. Rothery (1996) suggested that after text deconstruction by the teacher, the students should be engaged in a joint text construction, where the teacher and students create a text collaboratively as a means of applying the features of the text deconstructed. Joint text construction allows the students to get instant feedback on how their use of language in their writings could be further improved to meet the writing convention and to get assurance that they are in the right track in applying the writing tips given.

In terms of the students' report writing, considering that it was the first time the students had the chance to write them, the students were able to produce reports that could resemble typical scientific reports. There are, however, a few areas that still need some improvements: authoritativeness and organisation of the rhetorical moves. The lack of authoritativeness in the reports could suggest that the students were not familiar with the writing genres of the science discipline. The interactivity exhibited in the reports could suggest that they were more familiar with other 'everyday' texts such as blogs or magazine articles which value interactivity with readers. In terms of rhetorical move structure, the missing moves 5, 6, and 7 could suggest that the students did not value conclusion and reference sections. The audience of the reports was secondary school chemistry students themselves. It is thus possible that they wrote the reports with themselves in mind, writing what they would like to see or treating the reports as a mere summary for the topic. Despite the missing moves, the reports did meet the intended communicative purpose, which was to inform and educate secondary school students on various environmental issues. The missing moves, while affecting the quality of the reports in terms of scientific conventions, did not affect the achievement of that objective.

Implication

The present study implies there is a value in explicitly teaching students the structure of scientific texts by deconstructing model texts to show the features and providing pedagogical opportunities for students to write. This is essentially a genre-based pedagogy that is typically adopted in language classes. While science class is certainly different from language class, science teachers can still consider genre-based pedagogy in science classroom to teach scientific writing. The present study focused on report writing, but there are also other important writing genres in science that students need to be familiar with. For instance, the genres of explanation and argument are essential to science learning and ought to be taught to students (Tang 2016a; Putra and Tang 2016). The complex nature of these two genres warrants teachers to guide students explicitly and help them understand how to write an explanation or an argument and why these genres are necessary. These writing skills are important for both science content mastery and communication competency in the twenty-first century. After all, students have to write for their science examinations, and should they decide to participate in the science discipline in the future, they have to be able to communicate their scientific ideas and findings.

Conclusion

The present study has shown how the teacher Kathryn taught report writing in a chemistry class. Kathryn explicitly taught the important features of scientific report and deconstructed a sample report to show the features to students, along with providing worksheets and rubrics as writing supports. The outcome of the teaching was that the students' reports, for the most parts, resembled typical scientific reports in terms of linguistic features and rhetorical move structures. The findings of the present study suggest the need for more genre-based pedagogy in science classrooms in order to teach and support students' writing in science.

Acknowledgment This paper refers to data from the research project 'Developing Disciplinary Literacy Pedagogy in the Sciences' (OER 48/12 TKS), funded by the Education Research Funding Programme, National Institute of Education (NIE), Nanyang Technological University, Singapore. The views expressed in this paper are the authors' and do not necessarily represent the views of NIE.

References

Bhatia VK (1993) Analysing genre: language use in professional settings. Routledge, New York
Chafe WL (1982) Integration and involvement in speaking, writing, and oral literature. In: Tannen D (ed) Spoken and written language: exploring orality and literacy. Ablex, Norwood, pp 35–53
Crawford M, Galiatsos S, Lewis AC (2011) The 1.0 guidebook to LDC: linking secondary core content to the common core state standards. Retrieved October 23, 2013, from http://www.literacydesigncollaborative.org/
Cresent Public Schools (n.d.) Science essay evaluation rubric. Retrieved March 12, 2014, from http://crescentok.com/staff/jaskew/WebBased/essayeval.htm
Eggins S (1994) An introduction to systemic functional grammar. Pinter, London
Fang Z (2005) Scientific literacy: a systemic functional linguistics perspective. Sci Educ 89(2):336–347
Fang Z (2014) Preparing content area teachers for disciplinary literacy instruction. J Adolesc Adult Lit 57(6):444–448. http://doi.org/10.1002/jaal.269
Fang Z, Wang Z (2011) Beyond rubrics: using functional language analysis to evaluate student writing. Aust J Lang Lit 34(2):147–165
Graddol D, Leith D, Swann J, Rhys M, Gillen J (2007) Changing English. Routledge, London
Halliday MAK (1994) An introduction to functional grammar. Edward Arnold, London
Halliday MAK, Martin JR (1993) Writing science: literacy and discursive power. The Falmer Press, London
Hillman A (2013) A literature review on disciplinary literacy. J Adolesc Adult Lit 57(5)
Hyland K (2007) Genre pedagogy: language, literacy and L2 writing instruction. J Second Lang Writ 16(3):148–164. http://doi.org/10.1016/j.jslw.2007.07.005

Lee KC (1978) Syntax of scientific English. Singapore University Press, Singapore

Lee KC (1983) Language in science and technology. In: Language and language education. Singapore University Press, Singapore

Lee O, Fradd SH (1996) Literacy skills in science learning among linguistically diverse students. Sci Educ 80(6):651–671

Lee CD, Spratley A (2010) Reading in the disciplines: the challenges of adolescent literacy. Carnegie, New York

Martin K, Miller E (1988) Storytelling and science. Lang Arts 65(3):255–259

Moje EB (2007) Developing socially just subject-matter instruction: a review of the literature on disciplinary literacy teaching. Rev Res Educ 31(1):1–44

Monash University (2007) Writing in science. Retrieved March 12, 2014, from http://www.monash.edu.au/lls/llonline/writing/science/6.xml?accessible=true

Pearson PD, Moje EB, Greenleaf C (2010) Literacy and science: each in the service of the other. Science 328(5977):459–463. http://doi.org/10.1126/science.1182595

Putra GBS, Tang K-S (2016) Disciplinary literacy instructions on writing scientific explanations: a case study from a chemistry classroom in an all-girls school. Chem Educ Res Pract 17(3):569–579. http://doi.org/10.1039/C6RP00022C

Rothery J (1996) Making changes: developing an educational linguistics. Lit Soc:86–123

Schleppegrell M (2002) Linguistic features of the language of schooling. Linguist Educ 12(4):431–459

Schleppegrell M (2004) The language of schooling: a functional linguistics perspective. Lawrence Erlbaum Associates, Mahwah

Shanahan T, Shanahan C (2008) Teaching disciplinary literacy to adolescents: rethinking content-area literacy. Harv Educ Rev 78(1):40–59

Shanahan T, Shanahan C (2012) What is disciplinary literacy and why does it matter ? Top Lang Disord:1–18

Swales J (1981) Aspects of article introductions. University of Michigan Press, Ann Arbor. http://doi.org/10.3998/mpub.3985899

Swales J (1990) Genre analysis: English in academic and research settings. Cambridge University Press, Cambridge

Tang K-S (2016a) Constructing scientific explanations through premise–reasoning–outcome (PRO): an exploratory study to scaffold students in structuring written explanations. Int J Sci Educ 38(9):1415–1440. doi:10.1080/09500693.2016.1192309

Tang K-S (2016b) How is disciplinary literacy addressed in the science classrooms? A Singapore case study. Aust J Lang Lit 39(3):220–232

Tang K-S, Ho C, Putra GBS (2016) Developing multimodal communication competencies: a case of disciplinary literacy focus in Singapore. In: Hand B, McDermott M, Prain V (eds) Using multimodal representations to support learning in the science classroom. Springer, Cham, pp 135–158. http://doi.org/10.1007/978-3-319-16450-2_8

Ure J (1971) Lexical density and register differentiation. In: Perren G, Trim JLM (eds) Applications of linguistics. Cambridge University Press, London, pp 443–452

Wellington J, Osborne J (2001) Language and literacy in science education. Open University Press, Buckingham

Chapter 5
Exploring 'The Thinking Behind the Doing' in an Investigation: Students' Understanding of Variables

Ryugo Oshima and Ros Roberts

Abstract Recent curriculum developments emphasise that scientific practice involves understanding about evidence. The concepts of evidence have been identified as 'the thinking behind the doing' and have been validated as a knowledge base underpinning this understanding, and we contrast this conceptual approach with the widespread 'process approach' in which the understandings may be implicit. One aspect of understanding is the validity of design and its underpinning variable structure. This small-scale exploratory questionnaire study, conducted with over 150 lower secondary school students from a school in Japan, enabled us to explore students' understanding of variables. Some items were answered well, suggesting students' competence with the ideas addressed, but interestingly a comparison of items that targeted similar understandings identified different responses. We tentatively suggest that the differences may be explained by students approaching the items from a 'doing' perspective – they may be imagining the stages they may go through, as if they were conducting the investigation – rather than from a 'thinking behind the doing' perspective wherein they would draw on their understanding of evidence, and specifically their understanding of variables, to respond to the items.

The Importance of Understanding Evidence

Over the years, how 'doing of science' has been conceived and expressed in the research, policy and assessment literature has differed. Some of the key developments and issues have been summarised by various authors (e.g. Glaesser et al. 2009; Hofstein and Lunetta 2004; Jenkins 2009; Kind 2013; OECD 2013). For a long time, the 'doing of science' was conceived in terms of various 'process skills'

R. Oshima (✉)
Chiba University, Chiba, Japan
e-mail: ryugo.oshima@chiba-u.jp

R. Roberts
Durham University, Durham, UK

J. Yeo et al. (eds.), *Science Education Research and Practice in Asia-Pacific and Beyond*, DOI 10.1007/978-981-10-5149-4_5

which were assumed to be ‘context-free’ and acquired through practice (Millar and Driver 1987). The process skills perspective is characterised by performance. The main characteristic of such a perspective is that the procedural component is to be learned by repeated exposure to practical work. The procedural component is largely implicit in teaching, and any guidance given to students is through a simple exemplification of the process (Abrahams and Millar 2008). Research has shown that ‘children failed to develop meaningful understanding under science-as-process instructional programs … but its legacy persists in both policy and practice’ (National Research Council 2007, p. 215). Elements of that legacy can still be seen in curricula that either have procedural components specified as behavioural objectives, since these may be translated into classroom practice and assessment as just ‘doing’, or in curricula that emphasise using investigations as a pedagogical approach, a way of teaching, mainly to illustrate substantive understanding. In such pedagogical approaches, the ‘doing’ of science is considered to be sufficient to meet the procedural component of the curriculum; students ‘discover’ the procedural element with practice.

However, recognition that the ‘doing’ is ‘supported by the *integration* of science concepts and processes, metacognitive processes, critical reasoning skills, and cultural aspects of science’ (Cavagnetto 2010, p. 337; emphasis added) has come to recent prominence. Many researchers (e.g. Lederman et al. 2014; Lubben et al. 2010; Roberts and Gott 2010; Schalk et al. 2013; Tytler 2007) have moved beyond describing what scientists do (wherein any understanding may be implicit) and explicitly articulate some of the ideas required to *understand* evidence since:

> At the core, science is fundamentally about establishing lines of evidence and using the evidence to develop and refine explanations using theories, models, hypotheses, measurements, and observations. (National Research Council, [NRC] 2007, p. 18)

The ideas required to understand evidence represent ‘the thinking behind the doing’ of science and have been termed the concepts of evidence. These ideas about evidence and their interrelationship underpin the overarching concepts of validity and reliability.

The knowledge base of evidence was developed with a detailed yet tentative specification given by Gott, Duggan, Roberts and Hussain (n.d.) and has been further exemplified by Gott and Duggan (2003). The premise is that these are a set of concepts to understand rather than processes to be mastered by practice. To emphasise the *conceptual* basis of evidence (in effect, no different to other concepts which we are familiar with in science), Roberts and Johnson (2015) have recently presented the interrelationships between some of the key constituent ideas required for decision-making as a concept map (similar to Fig. 5.1) and have shown how evidence is inherently related to the more traditional substantive knowledge and theories of science.

The map centralises the question of the validity of a pattern in data since the confidence in the validity in any research practice gives it weight as evidence for a claim – it is the validity or quality of the data that all investigators are striving for, regardless of what they are researching, and is at the forefront of investigators’

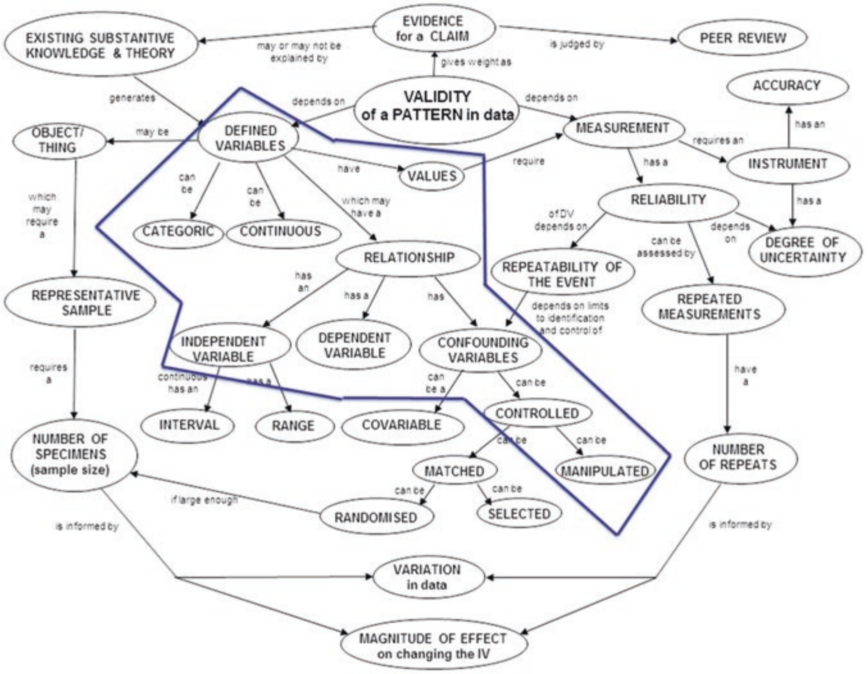


Fig. 5.1 A concept map of 'the thinking behind the doing' based on Roberts and Johnson (2015). The concepts and their interrelationships within the highlighted area are the focus of this research

thinking whether they are researching in a lab or the field, doing 'classical experiments' or 'observational study' (Gray 2014).

Understanding of the Variable Structure of an Investigation

At the heart of any investigation are variables (Roberts and Johnson 2015). Validly designed investigations attempt to explore the relationship between variables while reducing the effects of other potentially confounding variables. It is students' understanding of variables and their importance in the validity of the design of an investigation that is the focus of this research (Fig. 5.1).

All investigations involve defined variables. These variables are the basic structure of existing substantive (subject) knowledge – they constitute the disciplines of biology, chemistry, physics, earth science, etc. (Roberts and Johnson 2015). Variables can be categoric, having values which are descriptive (i.e. colour, substance, species), or continuous with values along a linear scale (i.e. length, volume). The nature of the variables' values in an investigation affects how patterns in data are presented graphically.

Variables may have a relationship with each other – a change in one may correspond to a change in the other. These two variables are identified as the independent variable (the IV) and the dependent variable (the DV), although other terms are sometimes used, such as input and output factors or, somewhat more simplistically, 'the thing we change' and 'the thing we measure'. To explore the relationship between the IV and the DV, the effects of any confounding variables which might also impact on the DV must be controlled in some way.

In the laboratory, typical of an 'experimental' approach, the ability to isolate and manipulate confounding variables so that their values can be controlled is exploited. Control variable (CV) values can be fixed at values that enable the relationship between the IV and DV to be validly explored.

Thus, an important element of students being able to understand evidence is that they can understand the interrelated ideas about the validity of the design of an investigation. We explore some aspects of this in this research.

Research into Students' Understanding of Variables

There has been extensive research into aspects of students' understanding of variables and their role in the validity of design (see National Research Council 2007, Chapter 5, for a comprehensive summary) conducted from different theoretical perspectives (Glaesser et al. 2009). Much has developed from a psychology (particularly Piagetian)-influenced perspective (Roberts and Gott 2008) where different aspects of reasoning have been studied, such as 'control of variables strategies', 'evaluation of covariance' and 'beliefs about causal mechanisms'. Our work overlaps with this, but the 'understanding ideas about evidence' perspective focuses on ideas integral to science and covers, as a consequence, more ideas from science than does the psychology-focused development of schemas.

Some research suggests that students can learn about variables' roles through 'frequent engagement with the inquiry environment alone' (NRC 2007, p 150), an extreme form of the 'process skills' approach discussed earlier. However, much interactive classroom practice will provide opportunities for prompts and questioning (of individuals or the whole class) via direct teacher interventions or through written prompts, and these have been shown to enhance understanding of variables (NRC 2007) although work in the UK suggests that many opportunities for this are missed by teachers (Abrahams and Millar 2008). Students' opportunities to engage with all the ideas about variables such that they can develop an understanding would therefore appear to be somewhat serendipitous. Roberts and Johnson (2015) have argued that the specification of the concepts of evidence and the consequent ability to then plan systematically for their teaching within a curriculum would be less haphazard.

The Context of This Research

The legacy of the 'process skills' approach – a 'doing' perspective – still exists in classroom practice, including in our experience in Japan. Students tend to conduct investigations wherein both the substantive ideas of the curriculum and scientific practices are illustrated.

In this research, we explore aspects of students' understanding in contexts familiar to them from their teaching, that is, in a lab-based experimental approach where variables can be isolated and manipulated.

The Research

Methodology

A total of 151 pupils aged 12–14 years in a municipal lower secondary school in Japan took part in the research in March 2014. They completed written surveys comprising questions about the variables involved in different scientific contexts. The answers were analysed to investigate students' understanding about the role of variables in an investigation.

Sample

Of the 151 students taking part in the survey, 60 were in Year 7 and 91 were in Year 8 in a municipal lower secondary school. In Japan, the school calendar begins in April and ends in March, so the Year 7 students had been at the school for almost a year and the Year 8 students had been there for almost two. Municipal schools recruit students locally, without any entrance examination: students simply enter a school in their school district. These schools follow the course of study (the national curriculum), and there is little variation between municipal lower secondary schools in terms of the grades attained by students in national tests (National Institute for Educational Policy Research 2012). These facts support that schools such as the one studied have a broad range of abilities, and we can reasonably assume that the one studied is fairly typical of other municipal lower secondary schools.

Questionnaire

The questionnaire was based on assessment items found in Gott et al. (1997). It consisted of a series of short response questions about the variables in the scenarios, and pupils had about 45 minutes to complete it anonymously. The questionnaire was composed of seven items, and each item included a few questions. Some questions were based on scenarios typical of the curriculum and which – according to their teachers – the students could be expected to be familiar with, for example, the addition of mass to a spring to determine its extension or the effect of changing the volume of water on the amount of alum that would dissolve. Other simple scenarios involved toy parachutes and the bending of a ruler. Scenarios involving both categoric and continuous variables were included. Figures 5.2, 5.3 and 5.4 are examples typical of the questions used.

In some questions students were provided with the question and conditions of an investigation and were asked to identify the variables involved. In others (e.g. see Fig. 5.2), headed tables of results were provided, and students were asked what the investigation must have been. In two items (shown in Figs. 5.3 and 5.4), students were asked to devise further similar questions they might investigate. There were also items about whether a variable was categoric or continuous and a multiple choice item about variable types and data presentation.

Questions were written in such a way as to concentrate on the students' understanding of variables, as follows: First, each question demanded only simple scientific knowledge, in order to reduce the difficulty of substantive knowledge, which might influence the results. Second, the questions which were presented to the students in Japanese were worded in a similar way, to reduce reading difficulty. For example, in item 2 students were asked to identify the IV, the DV and a CV in each question, for

Item 5: Tables 1, 2 & 3 show the results of three different investigations. What was tested in each experiment?

Table 1

Addition of mass to a spring (g)	Extension of the spring (cm)
50	1.4
100	2.9
150	4.5
200	6.1

Table 2

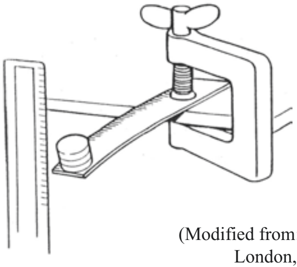
Type of material	Reaction when acid was added
Material A	Bubbled
Material B	No reaction
Material C	Bubbled

Table 3

Water temperature to dissolve alum (˚C)	Amount of water to dissolve alum (ml)	Amount of alum that would dissolve (g)
20	50	5.5
30	50	8.4
40	50	12.3
50	50	19.8

Fig. 5.2 Translation from Japanese of Questionnaire Item 5

Item 7 :This was written by Taro.
I tested the plastic ruler first. I clamped it to the table with 20 cm sticking over the edge. I then placed 3 metal weights right at the end of the ruler and measured how far the ruler bent. I did the same with the wooden ruler, making sure it stuck out by 20 cm and that the 3 weights were right at the end again. This diagram shows what I did.



These are my results.

Ruler	Amount it bent (mm)
Plastic ruler	34
Wooden ruler	17

(Modified from: Gott, R., et. al.: *Science investigations 1*,
London, Collins Educational, 1997, p. 51)

Q1: What question was Taro testing in this investigation?

Q2: Give three potential conditions that might affect the 'Amount it bent'.

Q3: Which condition did Taro change in this investigation?

Q4: What did Taro actually measure in this investigation?

Q5: Which condition did Taro keep consistent?

Q6: What did Taro find out from the result?

Q7: What other relationship could you investigate from the conditions identified in Q2 apart from the one that Taro tested? Write the relationship as a question that could be tested.

Fig. 5.3 Translation from Japanese of Questionnaire Item 7

Item 3:Daisuke had a question 'How does the diameter of a parachute affect the time it takes to land?' to test conditions to affect the time for aparachute to land.

Q1: Which conditions does Daisuke need to keep consistent to test his question? Give three conditions.

Q2: Give another two questions that could test other conditions that affect the time for the parachute to landas well as Daisuke's question.

Fig. 5.4 Translation from Japanese of Questionnaire Item 3

which Q1 was 'How is the maximum amount of alum that dissolves affected by the amount of water used?' and Q2 was 'How is the extension of a spring affected by the number of weights added?'. Third, examples of how to answer to the questions were clearly given to the students to reduce writing difficulty. This is because Japanese students seem not to be familiar with questions asking about procedural understanding. Fourth, the word 'condition' ('jouken' in Japanese) was used in the questionnaire instead of 'variable' because it is more commonly used in Japanese schools. For example, IV was converted to 'condition to change' in the questions. However, the term 'variable' is used in this paper to make the focus clear. Similar questions in English have been extensively used in research in the UK by Gott et al. (n.d.). We are aware that such linguistic differences may influence the students' responses.

Results and Interpretation

This research is exploratory and care must be taken when interpreting the results. These observations are therefore tentative.

Although we were interested in the students' understanding of 'isolated' items, we anticipated that the students would find many of the questions quite easy, and this was the case, with >70% of the sample giving correct responses to some items. For instance, the design of an investigation in terms of it having only one variable affecting the other by controlling the effects of others is familiar to Japanese students from primary school age; this 'controlling variables' is set as a main enquiry process to study at Year 5 in the course of study in Japan (MEXT 2008). We were aware, as well, that the items themselves may have acted as prompts to the students' reasoning (NRC 2007). So the generally high score on some individual items was unsurprising. However, the items in the questionnaire enabled comparisons between items that targeted similar understandings but from different perspectives so that we could explore a more holistic evaluation of the students' understanding – we could get beyond the responses to each isolated item and, through triangulation with ostensibly similar items, better establish whether students had developed a deeper understanding. By looking at the different responses, we were also able to infer how the students approached the items. We are aware that comparisons between small numbers of items must be treated with caution since other factors (such as the wording of the question) may have invoked different responses, but the differences we have identified are, we believe, worth further exploration.

The Context of the Question

The percentage of students with correct responses to some of the questions was high, suggesting that they had a good understanding of the underpinning ideas. For instance, students were asked to identify [item 2Q2] the IV, a CV and the DV in an investigation to answer 'How is the extension of a spring affected by the number of weights added?', and 84.1% identified the IV correctly and 70.9% the DV. However, when students were similarly asked to identify the IV, a CV and the DV in another investigation [item 2Q1] to answer 'How is the maximum amount of alum that dissolves affected by the amount of water used?', fewer (64.2% and 41.1%, respectively) identified the IV and DV correctly than in the spring investigation [item 2Q2] (Table 5.1). Only 31.8% were able to say what a table of results about dissolving alum [item 5Q3] (see Fig. 5.2) was investigating. The difference between the spring scenario and the alum may reveal what the students are thinking about when answering the question. In the spring scenario, as the investigator adds a mass (the IV, expressed in Japanese in the questionnaire as 'the condition to change') to the spring, the increase in length (the DV, expressed in Japanese as 'the thing to measure') is evident. However, in the alum scenario, the practical situation is less

Table 5.1 Percentage of variables identified correctly (Item 2 in the questionnaire)

	IV	a CV	DV
Q1: How does the maximum amount of alum dissolving into water change by an amount of water?	64.2%	20.5%	41.1%
Q2: How does the number of loads connected to the edge of a spring change by spring's expansion?	84.1%	84.1%	70.9%

directly obvious though this phenomenon itself is quite simple: the investigator would need several beakers (at the same time or sequentially) with different volumes of water (IV), and alum would have to be added, a little at a time, until no more would dissolve (DV). Yet from the students' perspective of 'doing', 'what you change' and 'what you measure' can readily be confused in this context – after all, the volume gets measured and they're changing the amount of alum added. Many students who failed in this question identified 'the amount of alum' as a CV. A possible reason for this is that a common practice in school practical experiments is for students to work by adding increasing amounts of alum to the water, either measured in equal-sized 'spoonfuls' or by tipping in alum that has been preweighed onto sheets of paper (to reduce the time it would take for students to weigh it themselves). So students might confuse 'the same amount of alum' (preweighed, on each piece of paper, or measured by the spoonful) as 'the condition not to change' and hence consider it is acting as a CV. In this scenario, answering the question from the perspective of 'doing' may have confused at least some of the students.

In another item [item 5Q1] (Fig. 5.2), when presented with a fully labelled table of results from an experiment looking at the relationship between mass and length of a spring, only 62.9% were able to say what the experiment was testing for. Responses like 'How will the expansion of the spring be changed by the weight of the load hung on the spring?' and 'How many cm will it expand with x grammes?' were both coded as correct responses since they identified – with varying degrees of clarity – both variables in the relationship. Although a correct response rate of 62.9% seems high, comparison with item 2Q2 suggests that, despite both items targeting the use of the same underpinning ideas, using information as if planning an investigation appeared to be easier than deducing what had been done. This supports our tentative interpretation of students being more familiar with the ideas in the context of 'doing' or that they are relying on tacit clues within the items themselves when responding. It seems reasonable to suggest that the students do not have a clear *understanding* of the variable structure of an investigation. Moreover, there is a possibility that students do not know that the IV and DV compose the framework of an investigation nor realise that an investigation's purpose is to explore the relationship between the IV and a DV. We come to this tentative conclusion because 32.7% of incorrect answers expressed the research theme of an investigation using just one variable, for example, 'the weight of the parachute' in item 3, even though examples of how to answer to the question had been given, and potential IVs were identified by themselves.

Categoric and Continuous Values

All scenarios in the questionnaire in which one or both variables had categoric values had lower scores than those in which with both variables were continuous despite categoric values being easier for students to handle in investigations (Gott and Duggan 2003).

Asked [item 6] whether variables had values expressed as numbers (continuous) or not (categoric), more than 90% of the continuous variables (94.0%, 92.7% and 96.7%) were correctly assigned. We have to be tentative in our claims since in three of the six questions the values in the questions were expected to be identified as categoric, but the students might have classified them as continuous since they could have been expressed as numbers, for example, colours are expressed not only by the words 'red', 'blue', 'green' but also in wavelength, and thus students who identified them as continuous variables are not strictly wrong. However, given the age of the respondents, it does not seem unreasonable to conclude that some were unable to distinguish categoric from continuous values. When presented [item 4] with a bar chart, a line graph or a pie chart and asked about how data from different investigations should be presented, the number of students who identified categoric data as being presented on a bar chart was only 31.8% compared with 55.0–66.9% for responses about continuous data and line graphs (Table 5.2).

With regard to a table of results [item 5Q2] showing the relationship between two categoric variables – types of material and whether they bubbled or not when acid was added – it was much harder for students to generate the question that this table represented (Table 5.3); 43.0% could do this, compared to 62.9% for a table [item 5Q1] showing two continuous variables which was a statistically significant difference (McNemar test was used; two-sided tests, $p < .01$). In the scenario shown in Fig. 5.3 [item 7Q1] with a categoric IV, only 53.6% correctly stated the question being investigated, compared with the 62.9% for two continuous variables in a table [item 5Q1] (Table 5.4). McNemar test was used, and this was marginally significant (two-sided tests, $.5 < p < .10$); however, a table of results and a picture were included in [item 7Q1] as a prompt, and this might be one of the reasons why the difference was not statistically significant. Overall, students' responses to all items involving

Table 5.2 Understanding of relationship between continuity of data and the ways of presenting

Questions	Ways of presenting data	Percentages
Q1: How does water height in a bathtub change by length pouring water?	Line	66.9%
Q2: How does an amount of leaves eaten by different insects in a day differ by kinds of insects?	Bar	31.8%
Q3: How does the maximum amount of alum dissolving into water change by an amount of water?	Line	59.6%
Q4: How does the number of loads connected to the edge of a spring change by spring's expansion?	Line	55.0%

Table 5.3 The result of item 5Q1 and item 5Q2

The number of students who answered		
	(In item 5Q2)	
(In item 5Q1)	Correctly	Incorrectly
Correctly	52	43
Incorrectly	13	43

Table 5.4 The result of item 5Q1 and item 7Q1

The number of students who answered		
	(In item 7Q1)	
(In item 5Q1)	Correctly	Incorrectly
Correctly	64	31
Incorrectly	17	39

categoric variables were less good than those involving continuous variables even though Duggan et al. (1996) report that continuous independent variables are more difficult to understand in an investigation than categoric values.

Categoric variables are usually taught prior to the introduction of continuous variables, and this is how it is presented in the Japanese curriculum. This sample of pupils had already progressed to working with continuous IV. If the students had developed a sound understanding underpinning their investigations, they might be expected to be able to work with categoric variables. Even if it is possible that students are able to think about whether a variable can be expressed in numbers or not, they do not seem to understand the connection with the graph type and the relationship that it represents. Students appear to lack the procedural understanding about continuous variables that a continuous IV and DV enable – using a display on a line graph – the details of the relationship to be seen. This implies that such an understanding should be taught explicitly.

CVs as Variables That Might Affect the DV

Students' recognition that confounding variables had to be controlled in an investigation was explored in many questions. When asked if heating an aluminium pan on a low heat and a copper pan on a high heat enabled the materials to be tested [item 1], 74.8% identified correctly that they couldn't be. Identification of variables that needed to be controlled in different scenarios, when a question identifying the IV and DV was presented [item 2Q2 = 84.1% correct; item 3Q1 = 72.2% correct; item 7Q2 = 64.2% correct; item 7Q5 = 72.8% correct], showed that identification of CVs was not a problem for most. Yet in two scenarios – that of investigating factors affecting how long a parachute takes to land [item 3Q2 = 45.0% correct] and Fig. 5.4's question 7 [item 7Q7 = ~40% correct] about other factors that could be investigated about the bending ruler – only about half of students were able to identify a variable that they had previously controlled as being a potentially new IV to answer a different question. Approximately 20.5% of other responses were incorrect. Incorrect responses did not identify both an IV and a DV in their response, for instance, 'dropping from the high place and the low place'. About 35.4% of students failed to respond at all, possibly a sign that they had not understood that CVs from an investigation were factors that might affect the DV and that could therefore be the focus of further investigation in turn. In addition, more than 70% correctly identified 'potential IVs' in item 7 as the 'CVs which were actually kept consistent in this investigation' in the same item. However, 28.5% failed to recognise that variables that had been controlled in one investigation (because they might impact on the DV) could be 'potential IVs' in another investigation with the same DV.

It seems that students have enough skills to identify variables but do not have an understanding about the relationships between variables (or that since CVs are variables that could affect the DV, they too could act as IVs) and the importance of variables in terms of the validity of the design of an investigation. This may also indicate that some students did not understand the underpinning variable structure of an investigation.

Further Discussion

We must be very careful in our conclusions. On the whole, this sample of students from a school that is reasonably typical of many in Japan seemed to be able to identify the IV, the DV and CV. The limitations of short response questionnaire items at really eliciting students' understanding are evident from our work and have implications for attempts to assess students' understanding with such items.

This preliminary work has identified some interesting differences in some students' responses which may suggest that they have a less secure *understanding* of variables than responses to isolated questions suggest. Further in-depth work, interviewing the students while answering questions about a range of other scenarios is called for.

We have only limited clues about the different responses to some items. But a possible explanation for all the observations noted above is that some students have a limited understanding of the variable structure of an investigation and instead approach the items as 'process', as if they were imagining doing it, a possible consequence of 'science-as-process instructional programs … [whose] legacy persists in both policy and practice' (National Research Council 2007, p. 215). This preliminary work's findings are not atypical of others' research into students' understandings of evidence (described earlier).

As shown in Fig. 5.1, we restricted the items to lab-based contexts in which control could be exerted by manipulating variables to maintain CV values, one of the simplest contexts to understand according to Roberts and Johnson (2015). Other ideas about variables shown on the map were not explored. The IVs used have all been relatively homogeneous, with little if any variation in type (e.g. alum, unless the sample was contaminated, has no variation; a spring, unless overstretched, behaves like other springs). We have not yet explored students' understanding in contexts where variables cannot be manipulated – in fieldwork or medical trials, for instance – nor have we explored their understanding of how the range and interval of IV values affect the validity of the pattern arising with the DV, nor how evidence is collected in investigations with variables which have inherent variation (such as 'sediment size in a stream' or 'people'). These understandings require more sophisticated understanding – called for in international comparisons such as *PISA 2015: Draft Science Framework* (OECD 2013) – yet such an understanding arguably depends on a strong foundation of ideas addressed here.

The Educational Implications

Work cited in Gott et al. (n.d.) shows that an understanding of the conceptual basis for evidence – 'the thinking behind the doing' – can be taught explicitly. This represents a cognitive approach to understanding evidence in contrast to the 'process' approach wherein mastery is assumed to be achieved through practice. The advantage of a curriculum conceived in terms of ideas to be understood is that it can be planned in the same way as any other aspect of the curriculum in terms of progression, coverage and pace.

Teachers may be unfamiliar with teaching from this perspective. Gott and Duggan (2003) have developed materials to support teachers' own understanding of evidence as well as resources that can be used in the classroom (Gott et al. 1997, 1998, 1999). Other suggestions for teaching can be found in Campbell (2010), Roberts and Gott (2002 and 2008).

Roberts and Johnson (2015) have presented the key understandings on a concept map, thus emphasising that evidence has a conceptual basis (in the same way that the 'substantive' ideas of science are conceived). They argue that the concept map of evidence is a means of representing the understanding of evidence necessary for these curriculum developments and exemplify the ideas and understanding with reference to two investigations that have been particularly useful in teaching.

We are not suggesting that teachers do not teach about the importance of the validity of design. It is usual for teachers to encourage students to identify variables and make a relationship between the IV, the DV and CVs in order to form a foundation of an investigation. To help students conduct valid investigations, teachers in Japan often use prompt sheets so that students can move on to the next step. However, as mentioned earlier, students in this context may be able to pick up clues from the sheet, identifying variables even when they do not have a sound understanding of them. Then, if the prompt sheets guide students almost automatically to the next step by letting students get away with just 'doing', they may not explicitly consider the understanding underpinning the validity of an investigation. So, when teachers teach, they should pay attention to the difference between routine approaches to 'helping students conduct valid investigations' and instead should be 'helping students consider the validity of a design of an investigation' to develop their deeper conceptual understanding (Oshima 2015). If the conceptual basis is not made explicit, students will likely miss the opportunity for cognitive development since their focus is just on ‘doing’.

We conclude from our results that students’ *understanding* of variables in an investigation would benefit from them being explicitly taught these ideas. Teachers should first adopt a higher-level ‘thinking perspective’ about variables in an investigation instead of a more routine ‘doing perspective’. For example, teachers have to be confident in their own understanding of evidence to teach explicitly and help students realise the need to examine the validity of the design of an investigation through identifying the role of variables. We argue that this requires a paradigm shift from a process view of identifying variables in the context of ‘doing’ to realising that there is an understanding underpinning validity of the design of an investigation. To put it in an extreme way, teachers should not be satisfied when students just identify variables correctly, but teachers can be satisfied when students are considering the validity of the design of an investigation, even if as they develop this understanding, they make mistakes along the way. Students’ understanding will take time to develop, and they will make mistakes just as they do when developing their substantive knowledge, although as their understanding develops they can be expected to understand the role of variables.

Success in teaching for a procedural understanding, for example, understanding variables, does not end with students conducting a valid investigation, but successful teaching will be evident when students are able to start considering the underpinning role of variables in the validity of the design of different investigations. It is the teacher’s key role that encourages students to consider the validity of the design of an investigation.

Acknowledgement We appreciate great cooperation from the students and teachers involved in this survey, especially Mr. Nobuya Takano and Mr. Ryuji Fujisawa. We could not have conducted this survey without your kind understanding and cooperation. We express our gratitude to you and your pupils here at the end of this paper.

References

Abrahams I, Millar R (2008) Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. Int J Sci Educ 30(14):1945–1969

Campbell P (ed) (2010) The language of measurement: terminology used in school science investigations. Association for Science Education (on behalf of ASE-Nuffield), Hatfield

Cavagnetto AR (2010) Argumentation to foster scientific literacy: a review of argument interventions in K-12 science contexts. Rev Educ Res 80(3):336–371

Duggan S, Johnson P, Gott R (1996) A critical point in investigative work: defining variables. J Res Sci Educ 33(5):461–474

Glaesser J, Gott R, Roberts R, Cooper B (2009) The roles of substantive and procedural understanding in open-ended science investigations: using fuzzy set qualitative comparative analysis to compare two different tasks. Res Sci Educ 39(4):595–624

Gott R, Duggan S (2003) Understanding and using scientific evidence: how to critically evaluate data. Sage, London

Gott R, Foulds K, Johnson P, Jones M, Roberts R (1997) Science investigations 1. Collins Educational, London

Gott R, Foulds K, Jones M, Johnson P, Roberts R (1998) Science investigations 2. Collins Educational, London

Gott R, Foulds K, Roberts R, Jones M, Johnson P (1999) Science investigations 3. Collins Educational, London

Gott R, Duggan S, Roberts R, Hussain A (n.d.) Research into understanding scientific evidence. Retrieved 30th Sept 2014 from http://community.dur.ac.uk/rosalyn.roberts/Evidence/cofev.htm

Gray R (2014) The distinction between experimental and historical sciences as a framework for improving classroom inquiry. Science Education Published online 10 January 2014 in Wiley Online Library wileyonlinelibrary.com

Hofstein A, Lunetta VN (2004) The laboratory in science education: foundations for the twenty-first century. Sci Educ 88(1):28–54

Jenkins E (2009) Reforming school science education: a commentary on selected reports and policy documents. Stud Sci Educ 45(1):65–92

Kind PM (2013) Conceptualising the science curriculum: 40 years of developing assessment frameworks in three large-scale assessments. Sci Educ 97(5):671–694

Lederman JS, Lederman NG, Bartos SA, Bartels SL, Meyer AA, Schwartz RS (2014) Meaningful assessment of learners' understandings about scientific inquiry – the Views About Scientific Inquiry (VASI) questionnaire. J Res Sci Teach 51(1):65–83

Lubben F, Sadeck M, Scholtz Z, Braund M (2010) Gauging students' untutored ability in argumentation about experimental data: a South African case study. Int J Sci Educ 32(16):2143–2166

Millar R, Driver R (1987) Beyond processes. Stud Sci Educ 14(1):33–62

Ministry of Education, Culture, Sports, Science and Technology in Japan (MEXT) (2008) The Course of Study for primary school. Tokyo Shoseki

National Institute for Educational Policy Research, Japan (NIER) (2012) The national survey on students' achievement test: commentary of the result. http://www.nier.go.jp/12chousa/12kaisetsu_chuu_rika.pdf

National Research Council (2007) Taking science to school: learning and teaching science in grades K-8. The National Academies Press, Washington, DC

Organisation for Economic Co-operation and Development (2013) PISA 2015: draft science framework. Author, Paris

Oshima R (2015) Characteristics of teaching methods for defining variables in England's teaching materials for scientific enquiry skills: findings from the perspective of promoting cognitive processes. J Res Sci Educ 55(4):405–414

Roberts R, Gott R (2002) Collecting and using evidence. In: Sang D, Wood-Robinson V (eds) Teaching secondary scientific enquiry. ASE/John Murray, London

Roberts R, Gott R (2008) Concepts of evidence and their role in open-ended practical investigations and scientific literacy; background to published papers. https://www.dur.ac.uk/resources/education/research/res_rep_short_master_final.pdf

Roberts R, Gott R (2010) Questioning the evidence for a claim in a socio-scientific issue: an aspect of scientific literacy. Res Sci Technol Educ 28(3):203–226

Roberts R, Johnson PM (2015) Understanding evidence: a concept map for 'the thinking behind the doing' in scientific practice. Curriculum J 26(3):345–369

Schalk HH, van der Schee JA, Boersma KT (2013) The development of understanding of evidence in pre-university biology education in the Netherlands. Res Sci Educ 43(2):551–578

Tytler R (2007) Re-imagining science education: engaging students in science for Australia's future. Australian Council for Educational Research, Melbourne

Part II
Societal and Affective Dimensions of Science

Chapter 6
On the Convergence Between Science and Environmental Education

Justin Dillon

Abstract A growing number of 'wicked problems' faced by society including climate change and biodiversity loss need to be engaged with as sustainability challenges. Addressing such problems might appear to necessitate science educators and environmental educators working together. However, science education, which has tended to focus primarily on teaching knowledge and skills, and environmental education which is characterised by the incorporation of values and a focus on changing behaviours have, over the years, moved apart significantly. In order to address the wicked problems, a convergence of science and environmental education is now needed. One strategy might involve collaborative research among scientists, educators and the public which could link science and society with place and identity. The outcome of this convergence would be more effective processes of public engagement and learning that could result in meaningful socioecological outcomes. The data gathered and shared using information and communication technologies can provide useful input to scientists. At the same time, such projects can empower citizens to engage in debates about local and global environmental and sustainability issues. More importantly, perhaps, they can support the public in taking action to address the key issues and challenges faced by society.

Introduction

The theme of ISEC 2014 was to question 'the arbitrary boundaries that have shaped current practices and mindsets in science education' (NIE 2014). In that spirit, this paper examines the relationship between science and environmental education in the context of moves to 'develop scientifically literate global citizens' (ibid.).

My intention is to expand the argument I and colleagues made in a paper in *Science* a couple of years ago (Wals et al. 2014). We were approached by staff at the journal as we had recently published the first ever *International Handbook of Research on Environmental Education* (Stevenson et al. 2014), and they thought

---

J. Dillon (✉)
University of Bristol, Bristol, UK
e-mail: justin.dillon@bristol.ac.uk

J. Yeo et al. (eds.), *Science Education Research and Practice in Asia-Pacific and Beyond*, DOI 10.1007/978-981-10-5149-4_6

that we might have something to say that would interest their readers. I have to say that it was probably the most difficult paper to get accepted that I've ever been involved with. After numerous drafts and heavy editing by the journal, the final version made it into the journal. Because of *Science's* space constraints, the argument is condensed and the writing style somewhat terse. It also doesn't help that it was written by four people with somewhat differing ideas about what was the most important message.

The advantage of publishing in *Science* is that it reaches an audience beyond the normal readership of education journals. So far, our paper has been cited in *Current Opinion in Environmental Sustainability, Food Research International, Journal of Cleaner Production, Ecological Research, Land* and *Journal of Organisational Transformation & Social Change*. However, that diverse readership means that the message has to be simplified and yet convincing. Our paper summed up our key message as follows:

> We advocate support for collaborative research efforts among scientists, educators, and the public, linking science and society with place and identity, through more effective processes of public engagement and learning that can result in meaningful socioecological outcomes. The data gathered and shared using ICT can provide useful input to environmental scientists while simultaneously empowering citizens to engage in ongoing debates about local and global sustainability issues and what needs to be done to address them. (Wals et al. 2014, p. 584)

Our starting point in writing the *Science* paper was that a growing number of 'wicked problems' faced by society, such as climate change and biodiversity loss, need to be engaged with as sustainability challenges which, on first inspection, might seem to involve a natural liaison between science educators and environmental educators. However, as we pointed out:

> Regrettably, science education (SE), which focuses primarily on teaching knowledge and skills, and environmental education (EE), which also stresses the incorporation of values and changing behaviors, have become increasingly distant. The relationship between SE and EE has been characterized as "distant, competitive, predator-prey and host-parasite" (*2*). We examine the potential for a convergence of EE and SE that might engage people in addressing fundamental socioecological challenges.

In this paper, I will unpack some of these issues and outline the case for a convergence of science and environmental education. The first section of the paper looks at some of the challenges faced by science education.

Challenges Faced by Science Education

In *Science Education in Europe: Critical Reflections* (Osborne and Dillon 2008), we noted that while science education is widely regarded as being important for all school students, its nature and structure have rarely been adequately discussed. The school science curriculum has evolved rather slowly over a long period. The curriculum has often been heavily influenced by scientists who have regarded school science as a foundational preparation for a science degree. Such a curriculum, which invariably focuses on biology, chemistry, and physics:

> does not meet the needs of the majority of students who require a broad overview of the major ideas that science offers, how it produces reliable knowledge and the limits to certainty [and] both the content and pedagogy associated with such curricula are increasingly failing to engage young people with the further study of science. (*ibid*., p. 7)

We saw this as a major problem as:

> many of the political and moral dilemmas confronting society are posed by the advance of science and technology and require a solution which, whilst rooted in science and technology, involve a combination of the assessment of risk and uncertainty, a consideration of the economic benefits and values, and some understanding of both the strengths and limits of science. (*ibid*., p. 8)

Global climate change provides a topical example, and the question we posed was, 'Is it amenable to a technological solution or will it simply require humanity to adapt to the inevitable changes through measures such as better flood defences, improved water conservation and changes in agricultural land use?' (ibid.)

We argued for a new kind of science curriculum:

> To understand the role of science in such deliberations, all students, including future scientists, need to be educated to be critical consumers of scientific knowledge. Improving the public's ability to engage with such socio-scientific issues requires, therefore, not only a knowledge of the content of science but also a knowledge of 'how science works' – an element which should be an essential component of any school science curriculum. (*ibid*.)

However, I should point out that changing the curriculum will only work if there are changes in pedagogy. Unless teachers use different approaches to teaching about socio-scientific issues, then there will not be any change in student understanding and engagement. In this paper, I argue that some of the pedagogic approaches that might improve science education come from looking closely at what works in environmental education.

Finally, to illustrate that these issues are current and relevant to more than just the English context, a European Expert Group on Science Education has recently produced a report entitled *Science Education for Responsible Citizenship* in which the authors articulate 'a 21st century vision for science for society within the broader European agenda' (Expert Group 2015, p. 5). They suggest that an interdisciplinary approach is the way forward:

> Greater attention should be given to the value of all disciplines and how inter-disciplinarity […] can contribute to our understanding and knowledge of scientific principles to solve societal challenges. (*ibid*., p.30)

They also advocate stronger collaborations between schools and the rest of the education sector:

> Collaboration between formal, non-formal and informal educational providers, enterprise and civil society should be enhanced to ensure relevant and meaningful engagement of all societal actors with science and increase uptake of science studies and science-based careers to improve employability and competitiveness. (*ibid*, p. 10)

However, given the influence of international comparisons such as the OECD's PISA, it is unlikely that many countries, whether they do well or badly in such tests, would be likely to make radical changes to its school science curriculum. Until policy-makers realise that PISA is constraining change in science education rather than driving much needed change then nothing much will happen.

Challenges Faced by Environmental Education

In comparison with science education, environmental education is relatively new. For a number of reasons including being a newly emerging and contested area, it has undergone substantial changes over the past few decades (Stevenson et al. 2014).

Much of the early work in the area was driven by a positivist philosophy which reflected the quantitative psychological background of a number of US researchers.

> Initially, much research in EE (especially in the United States) focused on the effectiveness of EE activities in changing individual environmental behaviors. This approach contributed to the persistent but ill-founded assumption that there is a simple linear relationship between knowledge, awareness, attitude, and environmental behavior. Research, most notably from social psychology, has long revealed that this is far too simplistic an explanation of what affects people's actions (Wals et al. 2014, p. 583)

EE research nowadays tends to focus on examining how learners develop the competence or capacity to:

(i) think critically, ethically, and creatively in appraising environmental situations;
(ii) make informed decisions about those situations; and
(iii) develop the capacity and commitment to act individually and collectively in ways that sustain and enhance the environment. (ibid.)

In more recent years, the focus has shifted away from looking for simple linkages between educational interventions and desired behavioural outcomes. Indeed:

> More attention is now being given to an understanding of the learning processes and the capacities of individuals and communities needed to help resolve complex socioecological issues. This focus also calls for a better understanding of people's cognitive and emotional responses to environmental issues. These responses are influenced by their worldviews and belief systems, which in turn are linked to identity. For example, recent research has rendered problematic a focus solely on better comprehension of the science of climate change owing to "identity-protective cognition theory," which indicates that many people's positions on climate change are largely shaped by their political and religious affiliations and identities. (*ibid.*)

Early in the century, in the introduction to a special issue of the *International Journal of Science Education* on 'Perspectives on Environmental Education-related Research in Science Education', William Scott and I wrote that 'environmental education offers a conceptual richness that challenges current thinking in science education because of its multi-disciplinary origins and traditions' (Dillon and Scott 2002, p. 1112). We went on to comment that:

> Environmental education provides an opportunity to bring in modern and challenging social and scientific issues into the classroom that is currently hindered by the packed and conservative science curricula of many countries around the world. (*ibid.*)

Citizen Science

The convergence of science and environmental education that we advocated in the *Science* paper emerges in the guise of new approaches to 'citizen science'. I have been quite critical of many citizen science projects in the past for not really involving the public in science but for simply using them to 'crowdsource data' as my colleague Colin Johnson once remarked. However, the public involvement in the scientific enterprise – the Public Participation in Scientific Research (PPSR) – as Bonney et al. call it, has a long history dating back at least as far as 1880 when data about bird strikes were recorded by lighthouse keepers.

As well as getting some insights into some aspects of science, the public can benefit in other ways:

> Participants in many PPSR projects also gain knowledge of the process of science. Indeed, this is one area where PPSR projects have the potential to yield major impacts, particularly Collaborative and Co-created projects, which engage participants in project design and data interpretation to a significant degree. (Bonney et al. 2009, 12)

Projects involving collecting data using simple test kits or straightforward observation techniques (such as counting numbers of birds) seem to me to be at one end of a spectrum of PPSR. But new technologies have meant that the public engagement can be much more sophisticated and, perhaps, more scientific:

> Citizen science most often refers to community-based local monitoring of changes in the environment using simple data acquisition devices and communication tools. More recently, CS has taken advantage of the Internet, social media, and mobile applications in crowdsourcing scientific data—resulting in what we refer to as ICT-supported CS. This trend connects well with recent EE research that identifies the use of social media as well as technology-enhanced citizen data acquisition as a way to enhance the interaction between research in science, education, and the environment. (Wals et al. 2014)

In a relatively recent review, Dickinson et al. (2012) argued that citizen science is expanding ecology and the biological sciences related to global climate change.

> citizen science pushes the envelope of what ecologists can achieve, both in expanding the potential for spatial ecology research and in supplementing existing, but localized, research programs. The primary impacts of citizen science are seen in biological studies of global climate change, including analyses of phenology, landscape ecology, and macro-ecology, as well as in sub-disciplines focused on species (rare and invasive), disease, populations, communities, and ecosystems. Citizen science and the resulting ecological data can be viewed as a public good that is generated through increasingly collaborative tools and resources, while supporting public participation in science and Earth stewardship. (Dickinson et al. 2012, p. 291)

The idea of Earth stewardship can be fostered in a number of ways in school:

> For instance, by creating "edible gardens" […] schools can, with the involvement of a wide range of societal actors (e.g., a local garden center, a restaurant, a community organization, and the local government), simultaneously improve the quality and relevance of their education and transform their relationship with the local community (15). Soil preparation, seed selection, planting, maintaining, harvesting, and preparing a meal require basic scientific knowledge that connects with the SE curriculum while also creating other benefits, such as community engagement, learner empowerment, improved personal health, and a better connection with food and place. Wals et al. 2014, p. 344)

Some years ago, I visited the Edible Schoolyard in Berkeley, California. It is a 0.4 ha garden which was established in 1995 by a local restaurateur and activist, Alice Waters, at Martin Luther King Junior Middle School. The Edible Schoolyard has been an inspiration for a number of other initiatives and is a good example of the kind convergence that might prepare students for living in the world of today and tomorrow.

Another way in which Earth stewardship might be fostered in this case using information technology is the YardMap[1] project. YardMap encourages collaboration between users and scientists, and using Google Maps and the YardMap interface, the public can map their own back gardens or local open spaces. The project was created by the Cornell Lab of Ornithology (CLO) and is designed to help users to improve the quality of local habitats for the benefit of visiting birds.

> YardMap is also the world's first interactive citizen scientist social network. When you join you are instantly connected to the work of like-minded individuals in your neighborhood, and across the country. Together you can become a conservation community focused on sharing strategies, maps, and successes to build more bird habitat.

The CLO hosts a number of other citizen science sites including the Great Backyard Bird Count,[2] Celebrate Urban Birds,[3] Project FeederWatch[4] and NestWatch.[5] In the UK, a number of citizen science project have been set up over the years including OPAL[6] (Open Air Laboratories) project. OPAL was launched in 2007 and since then more than 25,000 geographic sites have been examined by members of the public in collaboration with professional community scientists.

Although they are very popular, many citizen science projects offer participants little access to working in a scientific way or to solving their own problems. What we were arguing for in the *Science* paper was for citizen science projects which involved the public collaborating with scientists to identify their own research questions, codesign the research, collect data and benefit from its analysis. A recent guide to designing, implementing and evaluating citizen science projects noted that:

---

[1] www.yardmap.org

[2] http://birdcount.org/

[3] http://celebrateurbanbirds.org/

[4] http://feederwatch.org/

[5] http://nestwatch.org/

[6] http://www3.imperial.ac.uk/opal/aboutus

> In the right situations, citizen science can be extremely effective, not only for carrying out environmental surveys, wildlife recording or monitoring, but also for engaging people with how science works and for increasing their awareness of environmental issues and their local environment. One of the core strengths of the approach is that it can be used to present global issues - such as the impacts of climate change or biodiversity loss – in a way that is locally relevant and meaningful. For many people the opportunity to make a difference at the local level provides the motivation to get involved. (Tweddle et al. 2012, p. 2)

Final Thoughts

I began the chapter by noting that the theme of ISEC 2014 was questioning 'the arbitrary boundaries that have shaped current practices and mindsets in science education' (NIE 2014). I began by pointing out that science education and environmental education have moved apart over the years creating, to some extent, a rather arbitrary boundary between two fields of education. Now that we are faced by a series of 'wicked' problems such as biodiversity loss, food security, water security and climate change, we need to see a convergence between science education and environmental education.

Almost 15 years ago, the Australian EE researcher, Annette Gough, used the term 'mutualism' in arguing that science education and environmental education had much to offer each other. She wrote that 'Science education needs EE to reassert itself in the curriculum by making science seem appropriate to a wider range of students and making it more culturally and socially relevant' (Gough 2002, p. 1210). Addressing the issue of curriculum placement, Gough argued that:

> EE needs science education to underpin the achievement of its objectives and to provide it with a legitimate space in the curriculum to meet its goals because they are very unlikely to be achieved from the margins. (p. 1210)

My feeling is that is only possible if teachers are encouraged to change their pedagogies so that they empower students and their communities to work together to address their own sustainability challenges.

The ISEC conference focused on the need to rethink science education to encourage the development of 'scientifically literate global citizens' (NIE 2014). The notion of scientific literacy is contested, and some see it as almost a meaningless phrase. However, it will be around for a long time even if no one agrees on what it means. I am sympathetic with the view expressed in *Rethinking Scientific Literacy* by Roth and Barton (2004). In the book, they promote a radical view that scientific literacy 'emerges as a recognizable and analyzable feature of (collective) human struggle in which the child is but one part' (p. 75) and they propose a science education that 'acknowledges the limitations of science' (p. 177) arguing that:

> Acknowledging the nature of science as it is and can be practiced in the community opens the doors to richer understandings of science as a creative and perhaps imaginative activity, mediated by honesty in the face of agreed-upon evidence […] Such an approach permits groups and communities to enact different relations between scientific and other forms of

> knowledge (e.g. traditional, relational). Rather than privileging disciplinary science, we ought to foster situations that allow the negotiations of different forms of knowledge geared to particular (controversial) problems as these arise in the daily life of a community. (p. 177)

So, the challenge is to foster the convergence of science education and environmental education. This is a challenge of pedagogy as much as it is one of curriculum. It will require funding for innovative projects and professional development that supports and sustains change in and out of the classroom. For that to happen, we need visionary policy-makers and funders willing to rise up to the challenges faced by society.

References

Bonney R, Ballard H, Jordan R, McCallie E, Phillips T, Shirk J, Wilderman CC (2009) Public participation in scientific research: defining the field and assessing its potential for informal science education. A CAISE inquiry Group report. Center for Advancement of Informal Science Education (CAISE), Washington, DC

Dickinson JL, Shirk J, Bonter D, Bonney R, Crain RL, Martin J, …, Purcell K (2012) The current state of citizen science as a tool for ecological research and public engagement. Front Ecol Environ 10(6):291–297

Dillon J, Scott W (2002) Perspectives on environmental education-related research in science education. Int J Sci Educ 24(11):1111–1117

Expert Group on Science Education (2015) Science education for responsible citizenship. European Commission Directorate-General for Research and Innovation Science with and for Society, Brussels

Gough A (2002) Mutualism: a different agenda for environmental and science education. Int J Sci Educ 24(11):1201–1215

National Institute of Education (NIE) (2014) The International Science Education conference 2014 (ISEC 2014). Available at http://www.nie.edu.sg/events/isec-2014. Accessed on Aug 13 2015

Osborne J, Dillon J (2008) Science education in Europe: critical reflections. The Nuffield Foundation, London

Roth W-M, Barton AC (2004) Rethinking scientific literacy. RoutledgeFalmer, New York

Stevenson RB, Brody M, Dillon J, Wals AE (eds) (2014) International handbook of research on environmental education. Routledge, London

Tweddle JC, Robinson LD, Pocock MJO, Roy HE (2012) Guide to citizen science: developing, implementing and evaluating citizen science to study biodiversity and the environment in the UK. NERC/Centre for Ecology & Hydrology

Wals AEJ, Brody M, Dillon J, Stevenson RB (2014) Convergence between science and environmental education. Science 344:583–584

Chapter 7
Science Education and Promises and Prospects of Interest

Steve Alsop

Abstract This chapter offers some reflections on affect and measurement. In an era of high-stakes testing, I argue that there is an ever-present danger of overlooking important subjective aspects of educational research and practices. Interest has become a very popular measurement in science education influencing policy reforms. It is commonly noted that secondary children lack interest in science. However, the politics of what gets to count as interest are rarely discussed. What might we be valuing in our interest in interest? How might we value interest differently? Where and when? What promises and prospects might such interests hold?

Introduction

This chapter is based on a keynote that I gave at the ICEC conference. At the time, my local educational jurisdiction, Ontario, Canada, was grappling with lower than anticipated test scores in a recent OECD study. The local headlines read 'Canada's students slipping in math and science', followed with a mixed proviso; 'Canadian scores above average, but well behind front-running students in Shanghai, China' (CBC 2013). Discussions of educational performance continue in Canada. I know that we are not alone in this regard. The conference was in Singapore, a country widely recognised for its practices of high-stakes testing. David Hogan et al. (2013: 58) comment on mixed effects of external testing in Singaporean schools:

> Singapore's national high stakes regime has had both positive and negative consequences for the quality of teaching and learning. On the one hand, it goes a long way towards explaining the clear-eyed focus, coherence and effectiveness of instructional practice and the underlying performative pedagogical orientation that underwrites it in Singapore. On the other hand, we also think that the national high stakes assessment system has resulted in a pedagogy that is intractably didactic rather than dialogical, compromised the epistemic quality and the transparency or 'visibility' (Hattie 2009, 2012) of learning processes during lessons, restricted the opportunities of students to engage in knowledge building work in class, and constrained the ability of the system to successfully introduce substantial and

---

S. Alsop (✉)
York University, Toronto, Canada
e-mail: salsop@edu.yorku.ca

J. Yeo et al. (eds.), *Science Education Research and Practice in Asia-Pacific and Beyond*, DOI 10.1007/978-981-10-5149-4_7

> sustainable pedagogical improvements despite a strong policy commitment to doing so as reflected in the two key policy documents of the past 15 years. *Thinking schools, learning nation* (TSLN 1997) and *Teach less, learn more* (TLLM 2004).

Tests reduce complex systems, educational processes, teachers and students to seductive numeric forms. Such representations invite comparison and thereby seem to evoke, perhaps a better word is demand, particular responses in teaching and policies. Theodore Porter (1997) writes more broadly of our profound trust in numbers, which he binds with associated promises and desires of greater objectivity. Measurements from a distance appeal, Porter suggests, because they offer bird's-eye views of social jurisdictions. Nevertheless, such measurements can mask complexities, ambiguities and intimacies found within all social practices. These are perhaps only apparent when experienced and scrutinised up-close.

The is little doubting that numbers are powerful. They offer bureaucratic officials ammunition to make decisions that have a moral 'appearance of being fair and impersonal' (Porter 1997: 8). They provide a language of authority to shape the entire educational jurisdictions without 'seeming to decide' (p. 8). Of course, we should never overlook that particular measurements value some things more than others. While we might value our measurements, our measurements can never be entirely set free from our values. Perhaps values and knowledge are rarely as separable as they might at first appear.

The focus in what follows is research that explores the construct 'interest'. My evolving argument is that ways that we measure 'interest' incorporates certain values, and thereby the 'interest' we measure becomes constituted with these values. My more general point is that measurements are simultaneously judgements, and as a consequence they carry particular affectations, promises, wishes and desires. What concerns me in my latest research is what I am conceiving as a loss of subjectivities in an educational era that increasingly strives for objectivity (through proliferating forms of measurement).

Science Education and Affect

I have a long history of interest in emotions and feelings in science education (see Alsop 2006, 2015). Most would agree that emotions, feelings and affect are central to science education. Indeed, this is often a starting point for a wide variety of research that concerns itself with improving teaching and learning. Periodically there are even associated calls for a fundamental shift in science education to focus much greater attention on affect. Nearly 30 years ago, John Head (Head 1989: 162), for instance, commented 'the affective area will prove to be crucial in research and curriculum planning in the future'. There have been similar calls over the intervening years with similar commitments. Although emotions are, perhaps, not the most popular area of study in our field, there is now a fairly substantive body of research concerning the ‘effect of affect in science education’, to use my previous words (Alsop 2006: 4).

Despite growing recognition and attention, emotions and feelings still seem distant in some ways. They carry hopes of unlocking fundamental features of education and thereby shaping lasting education reforms. Yet simultaneously they retain somewhat nebulous, fragile and illusionary qualities. There is something uncultivated, perhaps unruly, about emotions, more especially within science – a subject that prides itself with rationality, reason and objectivity.

There are many contrasting theories of emotions. These include psychological theories, evolutionary theories, psychoanalytical theories, neuroscience theories, physiological theories, evolutionary theories, sociological and cultural theories and others as well. Of late in social sciences and humanities, there has been somewhat of a renaissance in studies of emotions within the so-called affective turn (Clough 2010). While such diversity of scholarship seems liberating, it can be unsettling in its plurality. Emotions can mean quite different things to different researchers in different context and at different times. In this respect, emotions are difficult to tame and control. Distinctions, for example, are sometimes drawn between emotions and feelings often centring on the natural, biological and universal as opposed to the contextual, sociological and cultural. For some such distinctions matter deeply, while for others they are less important. Emotions are commonly conceived as internal states. The question how do you feel? is commonly met with a personalised, individual response, such as I feel tired or I feel excited. For others, emotions are far more social and external. Emile Durkheim’s (1966) early sociological work discusses emotions in crowds. Arlie Hochschild (1979) is a sociologist who writes of the ‘managed heart’, describing instances in which different social contexts manage our feelings. One widely discussed example is flight stewards who smile when asking passengers what they would like from the drinks trolley. Our hearts are ‘managed’ during such brief commercial exchanges. These affect our moods and can lead to commercial transactions as well as lasting memories.

Emotions, needless to say, are central to who and where we are. They are something that we all experience on a day-to-day, moment-by-moment basis. Given this, it does seem rather odd that in science education research, we need to keep reminding ourselves that they matter so deeply and profoundly. It is also perhaps perplexing that research and theorising have been unable to reconcile contrasting approaches to emotional meaning and study. There is no single grand-theory of emotions. Emotions it turns out are rather slippery and elusive. In what follows my analysis draws largely from Sara Ahmed’s (2004) cultural politics of emotions.

Interest, Motivation and Attitude [IMA]

As previously mentioned, there is a history of research in science education that focuses on emotions. There are a series of quite distinctive traditions that dominate our field. By far the most popular are studies of ‘interest’, ‘attitudes’ and 'motivation'. I restrict my reflections to the emotional construct 'interest', although I believe similar comments might be made about 'attitudes' and 'motivation'. As Potvin and Hasni (2014) note, while 'interest', 'motivation' and 'attitude' can be distinguished, they are usually extremely close, and in multiple instances, their meanings both overlap and blur.

So, my interest is research in science education on interest. In contrast to familiar practices of studying interest in classrooms, however, my approach is different. I turn around to focus on research itself. I'm interested in traditions of studies of interest in science education. I have a cluster of guiding questions: How do we study interest in science education? Where do we study interest? What interest(s) do we study? Why? What do we want from our studies of interests? How might we study interests differently?

With this focus my intent is not to enter into a debate about right or wrong, desirable or less desirable, research methods. My focus is on underpinning assumptions – the modes of thought and practices that underwrite our studies of interest (specifically in science education). The following quotation from Michel Foucault (1988) nicely elaborates my perspective:

> Critique is not a matter of saying that things are not right as they are. It is a matter of pointing out on what kinds of assumptions, what kinds of familiar, unchallenged, unconsidered modes of thought the practices we accept rest. (p. 154)

The Promise of Interest

Perhaps the first point to stress is that there have been hundreds of studies that have sought to measure interest in science education. Indeed, some of the most cited articles in the field are reviews of this literature (see, for instance, Osborne et al. 2003). By far the most popular approaches use quantitative research methods based on questionnaires. Potvin and Hasni's (2014) recent article offers a thorough review of 228 articles of this nature, all published in leading journals between 2000 and 2012 (indexed in the ERIC database). As the authors note, interest has recently become a part of the PISA international assessments. This is another indication, I suggest, of its popularity and influence.

Given that different researchers use slightly different methods and question sets when studying interest (see PISA, TOSRA and the ROSE project tests), it is not always as straightforward as it might seem at first to synthesise extant research into a series of consistent outcomes. Nevertheless, I suggest that the following three themes are now fairly widely recognised in the field (see Potvin and Hasni 2014, for further details):

- Gender differences are frequently recorded with boys often having slightly more interest in science than girls (especially at the elementary level). More significantly, when individual disciplines are disaggregated, boys express considerably

greater interest in physics and technology. While, biology is often preferred by girls although to a smaller extent and not in all studies.
- Age differences are also widely recorded, with older, high school students expressing less interest in science. A considerable number of articles highlight the elementary/secondary school transition period as significant point in declining interests. A cluster of different variables are linked with interest including 'self-efficacy' and 'positive school experience' (including out of school and inquiry lessons).
- Expressions of interest in science can be different in different countries. The ROSE project (2004), for instance, notes a trend that countries lower on the Human Development Index often have greater interest in science.

Potvin and Hasni (ibid: 112) conclude their review suggesting three next steps for interest research:

1. To deepen our understanding of some of the most ambiguous or controversial results, like the causes of the decline of interest
2. To confirm the most promising ones, like the effects of inquiry-based pedagogical designs
3. To look deeper into places that, for all sorts of reasons, research has not paid attention to, [including] assessments of interest that would not be obtained by other means such as opinion questionnaires

Why the Interest in Interest?

There has been so much attention granted to studies of interest in science education. As the previous discussions indicate, important empirical trends are now emerging, no doubt shaping future work and policy. The study of interest is a lively, generative, progressive research programme. Here my interest in interest, however, is less about emerging patterns or the associated methodological tensions of validity and reliability. I recognise that these are important, but I want to hold to my focus on cultural politics and values (Ahmed 2004).

There is little doubt that we value interest greatly. An interest in science is frequently seen as, perhaps, the most important aspect of scientific literacy (the science education 'golden chalice'). An interest in science has been linked to thriving national economies (see Schreiner and Sjoberg 2004) and a necessary response to a shortage of highly skilled personnel (see OECD 2007). For others, interest is an indicator of successful and innovative pedagogy, sometimes framed as an equity issue in response to marginalised students excluded from scientific careers and future life pursuits that might involve science through their lack of interest (see discussions in Anderhag 2014).

As teachers and researchers, we certainly value interest greatly. The interested science student is a desirable student. Interest is something that we wish for in both theory and practice. In policy, interest comes across as an *answer* to a variety of things, including stronger economies, efficacious classrooms and future interactions with science (as previously mentioned). But associated educational *questions* accompanying these answers are not always as clear as they might be. I wonder what might we wish for our interest(s)? What wishes might our interests be carrying? There is an ever-present danger when discussing such things as slipping into a self-referential logic of interest is good, because interest is good. Interested students are desirable because they are just desirable. Good students are interested students because they are good. And so on.

I wonder why interest is so important. There are, of course, numerous other emotions: what about joy, happiness, pleasure, surprise, awe, contentment, love and hope, to name but a few. Are these emotions comparatively less or perhaps even more important? Perhaps they are just different. Although I suspect that they frequently get taken up and counted as interest in our research. In this regard, interest, I suspect, has become a ubiquitous exemplar for positive emotions in science education.

There are precious few studies of other emotions (although I must acknowledge a very recent special issue of *Cultural Studies of Science Education* 2016, Vol. 11, Issue 43, which is pushing an envelope in this regard). But if you look for studies of anger, angst, anguish, annoyance, anxiety and apathy (to focus just on those starting with the letter ‘a’), there is only modest research, if any research at all. One might imagine that anger, annoyance and/or frustration are highly influential emotional responses in science education. But there is only one article, to my knowledge, in a major science education journal on ‘frustration’ (Ho 1996) and none that I am aware of on anger. In science education, it seems, we place nearly all our emotional eggs in the interest basket. I wonder what might we be overlooking with such a heavy emphasis?

Interest has a long history of research in psychology spanning over a hundred years. There are well-established traditions of studying interest, and our research in science education, of course, builds on such traditions. As Sara Ahmed (2004) points out, some emotions are more culturally desirable than others in particular contexts. She describes ways in which emotions map onto culturally established hierarchies often relating to their closeness to reason and rationality. Some emotions are thereby ‘elevated’ as ‘signs of cultivation’, while others are cast as inferior and ‘signs of weakness’ (p. 3). Ahmed links this reasoning to early evolutionary models, citing Charles Darwin:

> With mankind some expressions, such as the bristling of the hair under the influence of extreme terror, or the uncovering of the teeth under that of furious rage, can hardly be understood except on the belief that man once existed in a much lower and animal-like condition. (Darwin 1904: 13–14 cited by Ahmed 2004: 3)

Evolutionary theory presents some emotions as being a residue of much earlier, more primitive, less developed times. Perhaps interest appeals, in part, because it is one of the more rational emotions. Indeed, there is discussion about whether interest should count as an emotion at all (see Hidi and Renninger 2006). Perhaps it is an especially desirable emotion in science education because of its long association with the cultivated, rational mind. Whereas other emotions, such as anger or frustration (to give two examples), are considered more 'primitive' and thereby less desirable and need to be kept more closely in check. The point is some emotions have cultural status of being 'more attractive', while others less so. Perhaps what rumbles beneath these judgements is the familiar reference point of the rational mind – an imaginary of a mind set free from the burdens and impurities of feelings, emotions and the body. Some emotions are considered more appealing because they are conceived more rational and more appropriate for a given cultural context.

While different emotions might have different cultural values, such designations are always likely over simplifications and generalisations. For instance, should interest always have a high status? Is interest always good? Is it always desirable? On occasions could it be bad or perhaps just indifferent or irrelevant. I suspect it depends. Perhaps the point is that interest is always *about* something, somewhere and at some point in time (Ahmed 2004). This needs to be taken into careful consideration. Is it possible, for instance, for children to be overly interested? Or what about overly self-interested? I think both need considering. If children are interested in something other than the intended focus of the lesson, one might imagine it less educationally harmonious and conducive. Perhaps this should count as 'disinterest' or 'interest in an undesirable way'. The general point is that context and orientation are clearly both important, especially I suggest, when discussing emotions. However, one of the associated problems of emotions is that we commonly value them as something without context, meaning or agency. This is a 'dumb view of emotions' to use Spelman's (1989: 265) term. With this viewpoint, emotions are not allowed to do anything – they are granted no/limited capacity to influence or act (Ahmed 2004).

We can ask similar questions of other emotions. Frustration might have a lower cultural status, but is it always bad? Might it be important? Might it be interesting (to confuse things even further)? It probably depends, once more, on what it is about. In science education, frustration is commonly linked with failure. The frustrated child is associated with lower academic achievements. But is this always the case? Indeed, a strong case can be made that frustration is quite central to both teaching and learning (perhaps even more so than interest). Many constructivist theorists, for instance, consider 'cognitive dissonance' an axiomatic feature of learning. In this light, it could be argued that frustration is an emotion of dissonance. In Piagetian terms, it might represent reactions to 'disequilibrium' and thereby act as an affective driving force for 'accommodation' and lasting conceptual change. I also suspect that frustration plays a key role in science. I'm sure that scientific research at times is highly frustrating. To conceive otherwise (I suspect) overlooks significant aspects of scientific achievements. Is the more 'modest' emotion of 'interest' able to drive complex scientific discovery, I wonder (see Haraway 1997).

Drawing from Ahmed (2004), my more general point is that emotions often have cultural legacies of being either 'good' or 'bad'. But this way of looking at them can be overly restrictive and unnecessarily limiting. For instance, I suspect that as a teacher I can find frustrated students frustrating in part because frustration is culturally conceived as a raw, unruly, less desirable emotion in education (in ways that interest is not). I now wonder how I might value frustration more in my educational research and pedagogy. In more general terms, might there be a danger in seeking to manage and suppress learners' frustrations too readily in our pedagogical practices? I wonder how I might take more emotions more seriously, which incidentally was the theme of my associated ISEC keynote.

An additional consideration here, of course, is intensity, duration and orientation. What emotional responses are about, their agencies, what they do and how they do it are all important. But this way of thinking about emotions is relatively unusual and has not been a central feature of sustained interest in science education research (or should this be a sustained frustration in science education research, I ponder).

I also wonder if our fixation on interest might be overlooking the need to repair more deep-rooted and systemic injustices and inequalities in classrooms. In science education research, adolescents and women repeatedly emerge as lacking interest (as the previous discussions indicate). But this is very much a deficit argument built on a comparative sense of lacking something. It leaves open what unique emotions adolescents and women might have in science classrooms, rather than what they seem not to have or what they are lacking. Perhaps a better understanding of these emotions might offer a firmer basis to respond to deep-rooted and persistent inequalities and injustices. This reframing somewhat sidesteps compulsions to change 'disinterested children' into 'interested ones'. After all, I wonder when students might have rights to be disinterested. As teachers and researchers, we must be careful not to overlook such rights and freedoms of expression.

Measuring Interest

As previously noted there is a diversity of ways that interest has been studied in science education. Some of these are much more situated, 'studies of emotions-in-science education contexts' (Alsop 2014). Excellent examples of this type include Jennifer Ann Jocz et al.'s (2014) classroom-based study of factors affecting student interest focusing on inquiry in Singapore classrooms and Per Anderhag's (2014) study of interest in a Swedish high school as constitution of a taste for science.

The most common studies of interest, however, are qualitative (not quantitative) in nature, derived from mainly questionnaires, often comprising of banks of 'Likert scales'. Once more, I am not questioning whether such approaches are right or wrong or desirable or less desirable. My point is that all research, whether qualitative, quantitative or mixed, has a series of opening assumptions. Here I reflect on some of the assumptions or values (my preferred term) underwriting these dominant studies of interest.

These studies generate data by encouraging participants to express preferences in response to written or spoken questions, often in the form of sliding 'Likert scales', frequently spanning poles, say from 'very interested' to 'not interested'. In this manner, they value individual responses on a common scale, recording and analysing differences on this scale. The interest that they value is thereby individualised and is assumed ‘universal’, varying only in degree (from strong to weak) and not in substance and form. My response to a question might be different to yours in intensity, but in order to make comparisons, interest is assumed to be the same affect (sensation) for both of us – otherwise comparative statistical analyses become undesirably compromised. If my ‘interest’ were entirely different to yours (other than in range/intensity), then large-scale comparisons and associations would become unmanageable or severely limited.

Moreover, questionnaires measure interest as a rational response to spoken or written questions. These are rational in the sense that research processes are generally not designed or encouraged to be an emotional experience but a reasoned, sedated ‘clinical’ exercise. It is expected that participants make judgements by weighing up various alternatives and making a personally revealing choice, such as a degree of interest in physics, biology, periodic tables, atomic chemistry and so on and so forth. This is largely a rational judgement of an emotional attachment, which is worthy of some reflection. It is also a decontextualised judgement made mostly from outside educational contexts. Questionnaires are rarely administered in educational settings, such as during lessons. They are mostly conducted in more peaceful, clinical environments far away from the hustle and bustle of classroom life. In this way they are, perhaps, more objectively appealing because they measure interest from afar (returning to Theodore Porter’s argument outlined in the early paragraphs). Paradoxically, such methods account for emotions in conditions designed to be as ‘unemotional’ or ‘uninteresting’ as possible. I wonder what would happen if this were to change. What would be lost and/or gained if we measure interest under research conditions designed to be really interesting (see Despret 2004)?

A more general point is that science education research has more dominant (and less common) ways of measuring interest. Dominant methods measure interest as individualised, universalised, rationalised, decontextualised and de-emotionalised. Other research methods might value interest in different ways and thereby account for different interests differently. With our present emphasis, I ponder what and whose interests might be getting overlooked?

Conclusions

In broad terms, this chapter has been a discussion of how we might value emotions, as well as how we might allow such emotions, meanings and values. I started by discussing some of the more influential ways that education is currently being measured. We live in an era in which international and national tests are demonstrably shaping policies and practices. In this era, we often value educational measurements from a distance. My concern is that as a consequence, some things are becoming overlooked in practice, research and policy. In part, I suggest that this is because they don’t easily show up on the radars of our favoured research methods. We value what we measure. But I believe we need much greater discussion of what our research values and, perhaps even more importantly, what it *ought* to value more.

The preceding discussions suggest we need more discussion of values in our education research on emotions, not only about how we might value different approaches to emotions but also how these approaches are themselves underwritten by different values. So how should we value interest in science education? What interests should we value? I believe that this discussion could fruitfully start by considering ways existing research methods value interest and how different methods might value quite different interests (rather than a single decontextualised static status, I think it is important to recognise interests in more situated, dynamic, performative and pluralistic terms). My concern is that some research practices have become so entrenched and normalised, and thereby other approaches are currently being overlooked and marginalised. I hope to extend these conversations in interesting ways in my ongoing research (see Alsop 2016).

References

Ahmed S (2004) The cultural politics of emotion. Routledge, New York

Alsop S (ed) (2006) Beyond cartesian dualism: encountering affect in science education. Springer, Dordrecht

Alsop S (2014) Affect in learning science. In: Gunstone D (ed) Encyclopaedia of science education. Springer Press, Dordrecht

Alsop S (2015) Encountering science education's capacity to affect and be affected. Cult Stud Sci. doi:10.1007/s11422-015-9692-6

Alsop S (2016) Afterword: science education and promises of emotion, aesthetics and wellbeing. In: Bellocchi A, Otel-Cass K, Quigley C (eds) Emotions, aesthetics and wellbeing in science education. Springer (in-press)

Anderhag P (2014) Taste for science: how can teaching make a difference for students' interest in science. Doctorate Thesis, Stockholm University

Ann Jocz J, Zhai J, Tan A-L (2014) Inquiry learning in the singaporean context: factors affecting student interest in school science. Int J Sci Educ. doi:10.1080/09500693.2014.908327

Canadian Broadcast Company [CBC] (2013) Canada's slipping in math and science, OECD finds. http://www.cbc.ca/news/canada/canada-s-students-slipping-in-math-and-science-oecd-finds-1.2448748 Last accessed 5 June 2016

Clough P (ed) (2010) The affective turn: theorizing the social. Duke University Press, Durham

Despret V (2004) Our emotional makeup. Ethnography and selfhood. Other Press, New York

Durkheim E (1966) The rules of sociological method (trans: Solovay SA, Mueller JH). The Free Press, New York

Foucault M (1988) Technologies of the self. In: Martin L, Gutman H, Hutton P (eds) Technologies of the self: a seminar with Michel Foucault. University of Massachusetts Press, Amherst, pp 16–49

Haraway D (1997) Modest_Witness@Second_Millennium. FemaleMan_Meets_OncoMouse. Routledge, London

Head J (1989) The affective constraints on learning. In: Adey P, Bliss J, Head J, Shayer M (eds) Adolescent development and school science. Falmer Press, London

Hidi S, Renninger K (2006) The fours-phase model of interest development. Educ Psychol 41(2):111–127

Ho CJ (1996) The effects of frustration on intellectual performance. Sci Educ 50(5):457–460

Hochschild A (1979) The managed heart: commercialisation of human feeling. University of California Press, Berkeley

Hogan D, Chan M, Rahim R, Kwek D, Aye KM, Loo S, Sheng YZ, Luo W (2013) Assessment and the logic of instructional practice in secondary 3 English and Mathematics classrooms in Singapore. Rev Educ 1(1):57–106

OECD (2007) PISA 2006: science competencies for tomorrow's world. Volume 1, analysis. OECD, Paris

Osborne J, Simon S, Collins S (2003) Attitudes towards science: a review of literature and its implications. Int J Sci Educ 23(9):847–862

Porter T (1997) Trust in numbers: the pursuit of objectivity in science and public life. Princeton University Press, Princeton

Potvin P, Hasni A (2014) Interest, motivation and attitude toward science and technology at K-12 levels: a systematic review of 12 years of educational research. Stud Sci Educ 50(1):85–129

Schreiner C, Sjoberg S (2004) ROSE: the relevance of science education. Department of Teacher Education and School Development, Oslo

Spelman E (1989) Anger and insubordination. In: Garry A, Pearsall M (eds) Women, knowledge and reality: explorations in feminist philosophy. Unwin Hyman, Boston

Chapter 8
Nature Teaches: Young Children's Experiences Learning Science Outdoors

Josephine M. Shireen DeSouza

Abstract The purpose of the study is to explore how young children learn science-related concepts when interacting with nature in an outdoor classroom. This study is also designed to examine how preservice education majors' perceptions of teaching inquiry are developed when they plan and teach young children in an outdoor field-based setting. Children are curious about their environment and learn through discovery. The direct experiences provided an opportunity for exploration and interactions with peers. Preservice teachers learned to use an inquiry-based instructional model in their planning for outdoor experiences.

Introduction

The inquisitive nature of young children urging them to engage in explorations and inventive behaviours mimics how scientists perform to generate knowledge. The learning process and understanding are fostered when young children participate in activities that are designed to promote investigation, solve problems and interact with peers. Even at an early age, all children have the capability and are predisposed to making observations and explorations and discovering their environments (National Research Council, 2012). In recent years there has been a paradigm shift in early childhood educational research, with a significant emphasis on studying child development and learning from a sociocultural-historical theory (Anning et al. 2008) perspective. The broad spectrum of theories and ideas purport that child development and learning take place through the external forces of interaction that children have with their peers, adults, teachers, families and the environment whether it is within the classroom or outside (Maynard et al. 2013). The rationale for providing environmental education in the early years is based on two premises. According to Wilson (1996), the first premise is that children should develop respect for living things and the environment in the first few years of their life or be at risk

---

J.M.S. DeSouza (✉)
Ball State University, Indiana, USA
e-mail: jmdesouza@bsu.edu

J. Yeo et al. (eds.), *Science Education Research and Practice in Asia-Pacific and Beyond*, DOI 10.1007/978-981-10-5149-4_8

at not developing those attitudes at all. Secondly, the positive interactions with the natural environment are very significant for healthy child development.

Theoretical Framework

The science-based curriculum by French et al. (2000) was designed for children to gain information and experience the interconnectedness in the world around them. Through participation in curricular activities, children developed receptive and expressive language skills, self-regulation of attention skills and problem-solving skills. Children's motivational beliefs and perceptions of competency are positive when they participate in integrated inquiry and literacy activities that nurture exploration during their kindergarten year (Patrick et al. 2008).

The Abecedarian Study (Campbell et al. 2002), a longitudinal research project that followed preschool children until they reached 21, found that those children who participated in consistent, quality early childhood education were more likely to score higher on standardised tests, enrol in and graduate from a 4-year college, delay parenthood and become employed. Thus, providing a stimulating educational environment to young children that nurtures their natural curiosity to learn science is likely to result in positive life-altering consequences.

National Science Teachers Association (2014) has identified key principles to guide the learning of science among young children. These principles are explicit recommendations for educators who make curricular decisions for young children, for the professional development and promotion of teaching science and for those individuals who are in the position of financing and making policy decisions for early childhood science education. The key principles are:

- Children have the capacity to engage in scientific practices and develop understanding at a conceptual level.
- Adults play a central and important role in helping young children learn science.
- Young children need multiple and varied opportunities to engage in science exploration and discovery.
- Young children develop science skills and knowledge in both formal and informal settings.
- Young children develop science skills and knowledge over time.
- Young children develop science skills and learning by engaging in experiential learning.

This research study takes into consideration the recommendations set by the National Science Teachers Associations (NSTA) that teachers and other educators should recognise the value of young children's curiosity and provide opportunities to guide and focus children's natural interests and abilities through carefully planned open-ended, inquiry-based explorations.

Early childhood educational research has, in recent years, focused on the importance of viewing child development and learning through the sociocultural or sociocultural-historical lens (Anning et al. 2008) rather than the observation that it is an individual achievement. Children are perceived to be maturing and learning in a social context which is characterised by interactions with people and materials within a particular place (Maynard et al. 2013). Most learning opportunities in preschools are provided indoors with blocks or toys; seldom is a natural setting considered a classroom where children can explore and experience endless occasions for discovery (Banning and Sullivan, 2010). Nature is experienced differently by children and adults. Adults perceive nature as a context for what they are focusing on, whereas nature is a haven for sensory experiences for children (R. Sebba 1991). They learn by using their senses leading to the development of curiosity, interest and imaginative skills. This study assesses the opportunity for young children to learn science concepts in a natural surrounding structured by the inquiry process and guided by the preservice teachers. As Rachel Carson (1956) has said, "If a child is to keep alive his inborn sense of wonder...he needs the companionship of at least one adult who can share it, rediscovering with him the joy, excitement, and mystery of the world we live in" (p. 45).

Research Questions

The research questions central to this study are "How do young children learn science in natural settings?" and, if they do, "Does the 5E instructional model aid in the learning process in an outdoor setting?"

Methodology

Subjects

Nature Teaches is a case study designed by the researcher in collaboration with a child development centre in Indiana, United States. The participants, who were enrolled in this centre, were 4 years old and would turn 5 years by August of that year. About 63% of the children at this centre are at or below poverty level and qualify for assistance. The participation of these 22 children was voluntary with no incentives except that they would be given free materials and an opportunity to learn science in the natural setting of Christy Woods, a Midwestern university campus in Indiana. Christy Woods is an outdoor learning laboratory for the university students and is also open for tours to the community. It is a 17-acre property of which two-thirds is covered by deciduous forests containing oak, hickory, ash, maple, hackberry and walnut. The centre open area divides the forest into east and west sections and is covered with tall grass prairie and native plants to Indiana. The researcher sent a letter to the parents informing them about the research and a description of the activities in which their child or guardian would be involved. The letter also explained the potential risks and benefits and a description of the measures that would be taken to protect the privacy and confidentiality of the participants. Child assent was also obtained before they participated in the activities. The other participants in the study were university students (24) who were enrolled in the course *Teaching Science in the Elementary School* in the summer session and were recruited through the course. The participation in a field experience was a requirement for the course; their lesson plans, observations of children's interaction with peers and adults in the learning process and reflections were also assigned activities for the field experience; however, their participation in the research study was completely voluntary.

Procedures

The summer session of the science methods courses runs for a duration of 5 weeks, and the preservice teachers meet three times a week for two-and-a-half hour. During the first week of the summer semester, the preservice teachers learned how to design inquiry-based learning activities in an outdoor setting, watched video tapes and practised making observations of young children interacting with their peers and adults as they would take turns to be participant observers. During the second week of the summer session, the field experience started at Christy Woods with the children arriving on a bus accompanied by their teachers from the child development centre. After the initial meet and greet session, the children were assigned to a group of preservice teachers who engaged them in an outdoor inquiry-based lesson. The design of the inquiry lesson followed the Biological Sciences Curriculum Study (BSCS) 5E instructional model (Bybee et al. 2006). The instructional model is based on the constructivist view of learning and has a sequence of planned instructional steps, engage, explore, explain, elaborate and evaluate, that provide students with experiential learning encouraging them to explore, build their own perception of the concept and be able to relate that understanding to other concepts.

Data Collection

The initial research question in a case study is linked to the data collection in a case study (Yin, 2009). There are three distinct areas of the 5E instructional model. One is the engagement and exploration stage of the lesson, the second is the explanation stage and the third is the elaborate stage. During each of these stages, the conversations between children and adults were recorded by the participant observers. Photographs of children in each of the groups were taken to document the learning process. In each group, two of the four preservice teachers took notes on observations that children made, questions that they asked and suggestions or possible explanations that they gave of the naturally occurring phenomenon in the three stages. While the two stages focused on learning concepts and developing science process skills such as observation, looking for similarities and differences and measuring, the elaborate stage involved pretend play, giving the children an opportunity to express their creative abilities. Each of the stages of the learning process was scheduled for 25 min. This schedule was repeated for three other sessions.

Preservice teachers were required to write lesson plans incorporating the 5E instructional model and write a reflection on the lesson they taught. Analysis of the lesson plans and written reflections and observations were conducted by the researcher. The lesson plans written by the preservice teachers are evidence of teachers' planning and use of inquiry-based practices and thus are important to this research study. The data collected from a variety of sources, namely, lesson plans, preservice teachers' observations and the reflections after teaching a lesson, were analysed. Within Christy Woods, there were designated areas chosen for instruction to take place. The preservice teachers chose these places based on the resources these places provided for teaching. For example, a clump of trees was an excellent spot to observe animals and birds. The prairies area provided a variety of flowering plants with bumble bees and butterflies. Fallen logs along the trail nested a wasps' nest, and the greenhouse gave shelter to exotic plants and orchids, while the Christy Woods classroom had a variety of taxidermy artefacts. To make complete use of the extensive wooded area, the preservice teachers rotated through the chosen locations so that the children would have ample space to move and run about without disturbing the other groups.

Analysis of Data

Banning and Sullivan (2010) critically examined the early childhood standards in the United States to identify learning behaviours and to apply them to their study on outdoor learning environments. As a result of their synthesis, a set of standards are derived, and corresponding indicators for each standard act as guidelines for early childhood educators. The teaching and learning behaviours were theoretically known in advance (Bybee et al. 2006); however, the responses of the 4-year-olds when exposed to this new environment were documented in the data that was collected. The themes that emerged from the inquiry-based lessons that gave the preschoolers an opportunity for inquiry, the observations of their interactions and the reflections of preservice teachers about the lessons they taught are listed in Table 8.1.

The first phase of the data analysis was to categorise lesson plans, the observations and the reflections after teaching based on the location of where the lesson was taught. Triangulation of data in a case study is typically used to increase the validity and reliability of the study by examining the researchers' interpretation of meaning. This interpretation is enhanced when we "assume the meaning of an observation is

Table 8.1. Summary of themes emerging from the qualitative data analysis

Inquiry Process	Observation of Lessons	Reflections
Creates interest, and curiosity	Children display curiosity and interest in learning	Encouraged by the children's enthusiasm for learning outdoors
Raises questions	Children ask questions	Children make good observations
Assesses prior knowledge	Children record and make observations	Surprised by how much the children knew
Makes observations of children' interactions	Children excited and share information	Children have short attention spans and get distracted easily outdoors
Children work together	Children interact with peers and use materials	Children helped each other with tools and materials
Facilitates pretend play	Children engage in pretend play	Children enjoyed pretending to be frogs, butterflies, and other animals
Uses children's prior experiences to explain	Answers open-ended questions	Children use pictures and communicate ideas through drawings
Guides children in exploration	Children enjoyed exploring the woods	Children look for differences and similarities
Evaluates students understanding of concepts	Children are able to connect ideas	Children are able to distinguish between living and non-living things, characteristics of animals, and plants

one thing, but additional observation gives us ground for revising our interpretations" (Stake, 1995, p. 110). In this study data source triangulation was used. Edwards (2010) recommends the use of a variety of data sources. The second phase of the analysis was triangulating the data from various sources (lesson plans, observations, reflections) for each session for a particular location. The data revealed an array of patterns of teaching and learning behaviours.

Findings

The findings of this exploratory case study augment our understanding of how young children learn science and how the 5E instructional model can be effectively used in an early childhood curriculum in a variety of outdoor naturalistic settings. The learning behaviours exhibited by the children and the preservice teachers' guided inquiry in each of the environments of Christy Woods are explained in the narrative below:

1. Children exhibited curiosity and interest in the natural surroundings.

Every day the children came by bus to Christy Woods accompanied by their teachers and were soon put into groups and assigned to a group of preservice teachers. The first lesson on trees was introduced by reading the book *The Giving Tree* by Shel Silverstein; one teacher reflected: *The students seemed interested in the tale of the little boy growing to adulthood with the aid of the kind tree. There was a moment* *near the end of the story that the children grasped an important concept that we wanted to convey. "Trees give a lot to us!" Randy said excitedly at the conclusion of the story. This comment could not have made me happier, as this was the sole reason for introducing the book and setting the tone for the lesson. "Randy that's true! But what exactly do they give us?" A flurry of answers came in an instant: shade, pretty colours, protection from rain and a home for animals.*

2. Children learn by making observations and using materials and tools.

While learning about trees, the children were given an opportunity to take bark rubbings from four different trees. They were supervised as they roamed in a small wooded area freely, comparing and contrasting the different types of barks. The preservice teacher reflects on the lesson he taught:

"Look at this one Lisa!" Faith exclaims excitedly, pointing to a tree with particular rough bark. The children were doing a masterful job at the rubbings, but more importantly they were completely engaged in the learning process without a conscious effort to do so.

The other lessons introduced students to a scavenger hunt in the woods. They were paired with a preservice teacher and went around looking for trees, leaves, nuts, flowers and animals that they could spot.

The students were once again very excited to explore once more and kept track of the items they saw by tallying on a sheet of paper. During this time, some students spent time looking at individual leaves to see how they were different, determine the size of rocks and keeping their eyes open for animals. One student in particular found a bird egg in a tree then spent more time looking for the nest. He was very proud of what he found and showed everyone in the group the bird's egg.

3. Children share ideas, assist each other and initiate interactions with their peers.

The nature walks into the woods gave children an occasion to talk to each other, share information and experiences and engage in a conversation replete with excitement and awe. One such episode that is characteristic of children's learning is depicted in the following conversation:

Ken: "I found a spider! Look how fuzzy it is!! Don't touch it". Remember we will take a picture of it guys".
Kayla: "Look, a tiny bug! I have good eyes; look, it's a baby!"
Carly: "Remember plants are alive and the ant is crawling on it!"
Kayla: "Remember we saw a chipmunk and squirrel last time!"

4. Children are receptive to new experiences, use their senses and marvel about the natural world.

The children were taught to differentiate between living and nonliving things. The hike along the trail brought many surprises and adventures that they would remember for a long time. Another preservice teacher reminiscing about her experiences describes the incident vividly:

The students really enjoyed exploring around Christy Woods, and they loved that we brought in some taxidermy creatures such as a squirrel and chipmunk. They embraced the notion that they were scientists for the day and took their magnifying glasses to explore the different plants and animals in the forest…. The most exciting part of the lesson was when one student found a very large cellar spider commonly referred to as a "daddy long legs" spider. The students really enjoyed using their magnifying glasses to get a closer look at the spider.

5. **Children rely on peer assistance and adult guidance providing information, materials and tools to do science.**

The activities in the various lessons required the children to use tools like magnifying lenses, digging implements, containers, insect collection boxes and clipboards. The children needed assistance in using them and frequently relied on their peers to help them. The following vignette is an example of how a preservice teacher finding no animals in their location improvised the activity. She reflects on what she did:

The students loved searching for animals and then recording their findings! We did have a few snags at this part though. There were not very many animals at all. Really, all we saw was a bird. Luckily, Ann and I tried to prepare for this happening. Before the lesson, I printed a big picture of each animal that we were going to look for. I placed them around Christy Woods in places that that animal would really live. For example, the squirrel picture was put on a tree. The students liked this almost as much as finding the real animal. They were just excited to hunt and explore for animals. Their journals turned out very well! They were actually way more detailed than I expected them to be.

6. **Children express their appreciation for nature by role playing and engaging in pretend play.**

Every lesson incorporated pretend play, and the children enjoyed participating in those activities. An example of the pretend play is described below:

We started out with a song, because we discovered the week before that the children loved to sing, so we wanted to incorporate that into our lesson, so we would be providing culturally relevant pedagogy for the students…. They loved the modification to "head, shoulders, knees and toes" that we did which included the addition of tails or paws to signify that animals can have different body parts than we as humans do.

Evaluating the Role of the 5E Instructional Model with Teaching Young Children in Outdoor Settings

Developed by the Biological Sciences Curriculum Study (BSCS), and published by Bybee et al. 2006, is a learning cycle based on a constructivist view of learning. The premise of the constructivist view is that the learner comes to the educational setting with some knowledge of how things operate around them. When new information is presented to the learner, and that information fits into the learners' repertoire of knowledge, it is easily assimilated. However, if the new information does not align to what the learner already knows, the learner has to rearrange their schema of thought to accommodate the information. According to Roger Bybee (1997), the objective of the constructivist model should be to encourage students to reexamine their notions through reflections and peer discussions in the context of the environment. The 5E instructional model while presented in a linear order – engage, explore, explain, elaborate and evaluate – is a learning cycle which the teacher facilitates for the students. In this study the preservice teachers used this instructional model to plan and prepare their lesson plans. An examination of the lesson plans and preservice teacher reflections after teaching gives us anecdotes of how they perceived the success of their teaching experience.

The **engagement stage** is designed to generate interest and curiosity among the learners. The teacher raises questions, to elicit prior knowledge and assess student understanding of the concept, including misconceptions. The lesson on *Soil and its components* was designed for the young learners to make observations of the soil and its many parts, through a variety of senses, and to be able to communicate their findings and predictions to their peers. Questions like "What is soil?", "Where can you find it?", "What is it used for?", and "What does it look like?" gave an idea of what the children knew about soil. To include literacy aspects to the science lesson, the book, *Dirty Gert* by Tedd Arnold was read, and the children were introduced to the term soil, so that they would transition into the next stage effortlessly.

A preservice teacher reflects, *by working with these young children, I have recognised their wants to explore and experiment things on their own. Even at the age of four, the students are asking questions about everything around them. The students would point out how some of the trees look different, leaves look different, flowers look different and how there were so many different animals and bugs in Christy Woods. With this thought, I believe that my philosophy of science education is very child-centred with the teachers as guides and facilitators.*

The **exploration stage** gives children an opportunity to work together using materials and tools appropriate for their developmental level. With the appropriate safety rules and precautions in place, the teacher observes and listens to the children interact. Probing questions guide the children through their investigations.

In this lesson, the children were given samples of soil in trays and were asked to examine it by feeling, smelling and observing its contents. After verbally communicating what they had observed, the children were paired up with a partner, and each pair was given a soil shaker (clear container) filled with water in it. The children had to predict what would happen if they shook the container. After shaking the container, the soil was allowed to settle. The students were then asked to draw what they saw in the container. During this very pivotal moment, a distraction presented itself.

The preservice teacher recalls, *during the lesson, the children were very excited to be outside. We placed our students underneath a tree. Unfortunately, I believe we placed them on an anthill. Marla and I had to adapt our lesson because of the ants that were everywhere. We did not want to stop the students from exploring the ants* *and using their imaginations. If the opportunity came up to talk about the ants, we stopped and listened to what they had to say. We encouraged them to be interested in the ants at appropriate times and tried to get them excited for the next week's lesson over insects.*

The **explanation stage** asks for proof and clarification from the student and uses prior experiences as a basis for explaining concepts. Students are encouraged to explain in their own words while the teacher provides scientific explanation and vocabulary.

The students illustrated what they saw in the soil shakers. The students were using their imaginations of what was really in the containers. It was amazing to see their thought process in this part of the lesson. I asked one little girl why all the larger pieces were at the bottom of the container. She answered me by saying, "They are bigger and heavier so they sink". It is amazing to hear that at such a young age that they understand things sink.

The **elaborate stage** expects students to apply concepts, skills and vocabulary to new situations. In this study, we had the children participate in pretend play. The play was teacher initiated and student guided. This was appropriate considering that the children had learned many concepts and skills and needed an avenue to express their feelings and appreciation for the natural world.

After the explanation, we moved the students away from the ants. We were going to let them build and explore the soil more. Since the students were so excited about the ants, we told them to build a home for an insect. I gave them more insects and worms to play with. We were just letting them use their imagination. At this moment, I was talking with a student. The student said, "I can't build a house because it is too dry". She understood that the soil needed to be thicker and be wet. We changed our lesson a little bit and added water to all the soil. The students love this part. They were having a great time just playing with soil that was mud.

During the **evaluation stage**, the teacher observes and assesses students as they apply new concepts and skills. Students are allowed to assess their own learning and group process skills. In this lesson the children explored the soil to find out "Which type of soil sticks the most?" They revisited the bottles of soil and the layers that they had drawn. They answered the question, "Why is soil so important?" They were also asked to consider what soil does for plants.

In conclusion, the 5E instructional model can be used with preschool age students and is very versatile in instructional strategy when applied to outdoor settings.

Impact on Early Childhood Teacher Preparation

This study has impacts on early childhood teacher preparation. Most preschools have playgrounds that are designed by architects and urban planners. The designed world has its own charm, but a natural outdoor setting has numerous benefits. In this study the participants both children and preservice teachers benefitted from interacting with each other. Children learned science concepts and made connections in the real world; they acquired communication skills, developed curiosity and collaborated on environmental activities with their peers.

It was Edward O. Wilson (1984) who described the biophilia hypothesis as an innate tendency for human beings to connect or be affiliated with natural and other forms of life. When the outdoor learning experiences are infrequently used due to harsh weather, Russian authors Shmis et al. (2014) describe that having large good-quality glass windows and displaying photographs of nature have a "biophilia effect" on the children. Getting this concept across to preservice teachers can be difficult when there are so few role models. In the words of one of the participants:

Before I took this class, I believed that science lessons were really just meant for inside activities for younger students. After this experience, I have come to realize that I was completely wrong. It was so much fun teaching the younger students. They are so young, but they understand concepts. I believe that in the future that I will have the knowledge to teach my students about science. It will be important for me to make sure that my lessons are hands-on and engaging. This will make it more exciting and memorable for the students.

The teachers' role in natural settings can be challenging; while the preservice teachers observed how children learn science, interact and develop social skills in the natural setting, they were surprised by the unexpected events the outdoors bring. The lesson on "habitats" brought the elements of the environment together. To teach children about the interconnectedness of the environment is a powerful learning experience.

Acknowledgements I would like to thank the Director of the Child Development Centre, the children and preservice teachers for making this study possible.

References

Anning A, Cullen J, Fleer M (2008) Early childhood education: Society and culture. Sage Publications, Los Angeles

Banning W, Sullivan G (2010) Lens on outdoor learning. Redleaf Press, St. Paul

Bybee RW (1997) Achieving scientific literacy: from purposes to practices. Heinemann, Westport

Bybee RW, Taylor JA, Gardner A, Van Scotter P, Powell JC, Westbrook A, Landes N (2006) The BSCS 5E instructional model: origins and effectiveness. BSCS, Colorado Springs 5:88–98

Campbell FA, Ramey CT, Pungello E, Sparling J, Miller-Johnson S (2002) Early childhood education: Young adult outcomes from the Abecedarian Project. Appl Develop Sci 6(1):42–57

Carson R (1956) The sense of wonder. Harper & Row, New York

Edwards A (2010) Doing early childhood research: International perspectives on theory and practice. Qual Design Anal 2:155–175

French L, Conezio K, Boynton M (2000) Using science as the hub of an integrated early childhood curriculum: The ScienceStart![TM] Curriculum

Maynard T, Waters J, Clement J (2013) Child-initiated learning, the outdoor environment and the 'underachieving' child. Early Years 33(3):212–225

National Research Council (NRC) (2012) A framework for K–12 science education: practices, crosscutting concepts, and core ideas. National Academies Press, Washington, DC

National Science Teacher Association (2014) NSTA position statement: early childhood science education. National Science Teachers Association, Arlington

Patrick H, Mantzicopoulos P, Samarapungavan A, French BF (2008) Patterns of young children's motivation for science and teacher-child relationships. J Exp Edu 76(2):121–144

Sebba R (1991) The landscapes of childhood: the reflection of childhood's environment in adult memories and in children's attitudes. Environ Behav 23(4):395–422

Shmis T, Kotnik J, Ustinova M (2014) Creating new learning environments: challenges for early childhood development architecture and pedagogy in Russia. Procedia-Social Behav Sci 146:40–46

Stake RE (1995) The art of case study research. Sage, Thousand Oaks

Wilson EO (1984) Biophilia. Harvard University Press, Cambridge. isbn:0-674-07442-4

Wilson RA (1996) Environmental education programs for preschool children. J Environ Edu 27(4):28–33

Yin RK (2009) Case study research: design and methods, 4th edn. Sage Publications, Thousand Oaks

Chapter 9
Affordances of Purposeful Play

Tang Wee Teo, Yaw Kai Yan, Woei Ling Monica Ong, and Mei Ting Goh

Abstract According to the Singapore Ministry of Education Kindergarten Curriculum Framework (Ministry of Education, Singapore, Nurturing early learners: a curriculum framework for kindergartens in Singapore. Retrieved on January 15, 2016 from http://www.moe.gov.sg/education/preschool/files/kindergarten-curriculum-framework.pdf, 2012), purposeful play is a pedagogical approach to actively engage children in exploring, developing, and applying knowledge and skills in an enjoyable manner. To achieve this broad objective, lessons have to be purposefully planned by taking into consideration children's interests and abilities. This chapter describes a group of Singaporean preschool children (aged 6) learning about ways to categorize different types of leaves through purposeful play at the Singapore Botanic Gardens. We discuss the affordances of purposeful play in this naturalistic learning context as illuminated through the teacher-student and student-student social interactions. Through this work, we want to demonstrate how purposeful play, when properly planned and capitalized on, could contribute to children's science experiential learning and understanding. Preschool teachers may be interested to learn how they can purposefully plan their lessons to create diverse affordances for children. This study also contributes to the early childhood literature, which has limited empirical studies about Singaporean preschool science education.

This manuscript is original and has not been submitted elsewhere for review or publication.

T.W. Teo (✉) • Y.K. Yan • W.L.M. Ong • M.T. Goh
National Institute of Education, Nanyang Technological University, Singapore
e-mail: tangwee.teo@nie.edu.sg

J. Yeo et al. (eds.), *Science Education Research and Practice in Asia-Pacific and Beyond*, DOI 10.1007/978-981-10-5149-4_9

Introduction

This chapter describes part of a larger study that aims to understand how Singaporean young children (aged 6–8) make sense of, participate in, and learn science. It describes an activity in which children learned about different ways to categorize various types of leaves through purposeful play (Fleer 2013) at the Singapore Botanic Gardens, a UNESCO heritage site. The research question addressed is:

> How and what affordances were created for Singaporean children engaging in purposeful play, during the activity on categorizing leaves, in the naturalistic setting of the Singapore Botanic Gardens?

Herein, we discuss the affordances of purposeful play in this naturalistic learning context as illuminated through the teacher-student and student-student social interactions. The aim of this chapter is to demonstrate how purposeful play, when properly planned and capitalized on, could contribute to children's science experiential learning and understanding. The findings of this study can inform preschool teachers on how they can purposefully plan their lessons to create diverse affordances for children. This study also contributes to the early childhood literature, which has limited empirical studies about Singaporean preschool science education.

MOE Kindergarten Curriculum Framework

In 2012, the document *Nurturing Early Learners – A Curriculum Framework for Kindergartens* (referred to as the "Framework" in this chapter) was published by the Ministry of Education (MOE), Singapore, "to guide pre-schools in designing and implementing a quality kindergarten curriculum for children aged four to six" (MOE 2012, p. 11). This framework resulted from a review conducted to update the scope and relevance of the guiding principles for classroom practices, with a view toward the development of twenty-first-century competencies among children at the preschool level.

Learning Areas

The *Framework* spells out six learning areas, namely, esthetics and creative expression, discovery of the world, language and literacy, motor skills development, numeracy, and social and emotional development. All learning areas comprise a set of learning goals that defines what children should be able to do at the end of their kindergarten education. These learning goals were translated into knowledge, skills, and dispositions to guide teachers construct quality holistic learning experiences for the children so that they may develop into confident persons, self-directed learners, active contributors, and concerned citizens (MOE 2012, p. 17).

Discovery of the World

Although science is not formally introduced in the Singapore curriculum until Grade 3 (aged 9), kindergarten children are introduced to science ideas through the learning area *Discovery of the World*. The goal of this learning area is to help children broaden their knowledge and acquire the essential skills and understanding to make sense of the world around them. It also aims to sustain children's natural curiosity to explore the world and lays the foundation for learning other subjects such as geography, history, and science.

Specifically, the learning goals defined for *Discovery of the World* (MOE 2012, p. 73) are for children to:

- Show an interest in the world they live in.
- Find out why things happened and how things work through simple investigations.
- Develop a positive attitude toward the world around them.

The skills to be developed through this learning area include observing, comparing, classifying, sequencing, asking questions, decision-making, problem-solving, predicting, testing, reflecting, reasoning, recording, and communicating (MOE 2012, p. 74). It is desired that the children will be able to (MOE 2012, p. 75) (a) observe and be aware of the world they live in, (b) carry out simple investigations to find out why things happen and how things work, (c) gather information from a variety of sources to find out why things happen and how things work, (d) make simple recordings of their observations and findings, and (e) talk about their observations and findings. These skills, knowledge, and dispositions are foundational to the learning of science and scientific practice (Osborne 2013). Such skills are important, not only for scientists but also for people in their everyday lives.

Purposeful Play in the Framework

Central to the *Framework* are the *iTeach* principles that guide the planning, designing, and facilitation of meaningful and appropriate learning experiences. The six *iTeach* principles are an integrated approach to learning, teachers as facilitators of learning, engaging children in learning through purposeful play, authentic learning through quality interactions, children as constructors of knowledge, and holistic development.

One of the *iTeach* principles is engaging children in *learning through purposeful play*. While *learning through play* was also featured in the earlier 2003 version of the framework, the emphasis was on providing opportunities for structured play involving a rich use of language. The revised *Framework* focuses on the crucial role that teachers play in creating the environment to enhance learning of the children. According to the *Framework*, purposeful play entails (a) enjoyment; (b) active involvement of children in exploring, deepening, and applying knowledge and skills; (c) addressing learning objectives that have been carefully thought through by the teachers while taking into consideration children's interests and abilities; and (d) facilitation by teachers who observe children at play to discover what they have learned and shaping their activities to reinforce or extend their learning toward intended objectives (MOE 2012, p. 35).

Given this background, the revised curriculum presents tremendous potential to explore innovative and fresh learning opportunities for preschool learners.

Purposeful Play and Its Affordances

In Marilyn Fleer's book titled *Play in the Early Years* (2013), she cited and elaborated on the characteristics of purposeful play described in the *Framework*. She highlighted the following five characteristics of purposeful play and associated each with specific roles of the adults and children, as well as the interaction between the two (Fleer 2013, p. 156):

1. *Authentic contexts are created to support learning and play*. Children are engaged in activities that are purposefully planned by the teachers taking the children into consideration, including learning goals which children can apply in their everyday lives.
2. *Collaborative learning is supported in play-based settings*. Children are actively involved in learning together with their peers, while the teachers employ various strategies to encourage this.
3. *Children take risks, make mistakes, and manage their own learning when playing*. Children take charge and are responsible for their learning, while the teachers remain sensitive to the children's needs and play a supportive role.
4. *In play-based situations, learning is enjoyable*. Play is planned by the teacher to be enjoyable for the children, and children see them as enjoyable.
5. *Play develops children's imagination and creativity*. Children use their imagination in the activity which aids them in being more creative, while the teachers remain sensitive to the children's needs and support them in their imagination and in arriving at more creative conclusions.

Purposeful play lies along a continuum of *child-initiated play* and *adult-initiated play* (Fleer 2013). In our current study, we see the level of initiation by the adult, and the child differs at different points within the same activity—the adult may suggest to the children to carry out a task, but during the activity a child may initiate a new idea or thing to do. Hence, instead of seeing purposeful play as being a fixed point on the continuum, we see it as moving along the continuum within an activity.

Although the concept of purposeful play per se has not been frequently examined in the literature, similar concepts have been invoked in some reported studies. In the following paragraphs, we list some examples of such studies and discuss how we see the characteristics of purposeful play being implemented therein.

A study based on *intentional teaching* [a pedagogy stated in the *Early Years Learning Framework* of Australia (Department of Education, Employment and Workplace Relations, 2009)] and *purposeful play* was conducted by Fleer and Hoban (2012). In this study, the authors examined how *Slowmation*, a stop-motion animation, can be used as a tool to bring about *intentional teaching*. One of the settings in their study was in a Singaporean preschool where the focus was on a 4-year-old child and a preservice teacher. The preservice teacher first observed the child at play with her grandparents and two uncles at a playground. Everyday concepts that the child used or constructed from her play were noted. A specific related scientific concept (force) was then chosen to be incorporated into the *Slowmation* activity. The *Slowmatio*n was based on a playground setting, in which the child and the teacher used two toys to represent one character each, and Plasticine was molded to represent various playground objects. We see the characteristics of purposeful play being fulfilled through the following: authentic contexts were present in the study as the context for the *Slowmation* was in the playground, and the concept incorporated into the *Slowmation* was decided based on prior observation of the child playing in the playground. In this study, collaborative learning was not enacted with peers as there was only one child. However, the child was observed at play with her family members at the playground, as well as cocreating the *Slowmation* with the preservice teacher. The activity may be enjoyable for the child as the *Slowmation* was based in the playground context, with two of her toys used as the two main characters of the story. Imagination was also included in the *Slowmation* as two toys were used as characters, playground objects were made using Plasticine, and a script was created for the conversation between the two characters.

Cutter-Mackenzie and Edwards (2013) examined how three different types of play pedagogies, namely, *open-ended play*, *modeled play*, and *purposefully framed play*, can help to support the learning and teaching of environmental topics. The authors defined *purposefully framed play* as including *open-ended play*, *modeled play*, and interactions between adult and children. Their study was conducted in Australia with a total of 114 children, aged 4–5, and 16 teachers. Prior to the implementation of the activities, the teachers underwent a training session where they discuss the three play types and possible concepts to be included. Each teacher then implemented the three play types to teach the children the specific environmental concepts that they have chosen. The children participated in the activities in groups of up to seven. Lesson videos, as well as teacher and children interviews, were collected as data. The characteristics of Fleer's (2013) purposeful play were discerned as follows. Authentic contexts were provided as teachers purposefully planned for a specific environmental concept as the learning outcome, and children can apply such concepts in their everyday life as it deals with the environment. Collaborative environments were in place as children participated in the activities in groups. In addition, the teachers used various strategies to facilitate their interactions with the children, with some of the strategies promoting collaboration among peers, such as group reflection. *Purposefully framed play* also included a period of *open-ended play*, which could likely be enjoyable for the children. In addition, the children's interests were taken into account when the teachers chose the specific environmental concept to incorporate in their implementation.

Some studies have also looked at *guided play*, which is seen to be mainly child initiated, but involve adults helping to scaffold the learning outcomes (Weisberg et al. 2013). We see this as being similar to purposeful play as it attempts to incorporate clear learning outcomes into play-based settings and places a focus on interaction between teacher and children. An example of a study that used *guided play* is that of Fisher et al. (2013), which compared three types of instruction, namely, *free play*, *guided play*, and *didactic instruction*, in the teaching of shapes to young children. Seventy children aged 4–5 took part in their study conducted in Philadelphia, United States. The children were assigned to one of the three instructional modes, by which they were taught about four different shapes. Thereafter, the children were tested for their knowledge on the four shapes. We see the guided play that was implemented in their study to be similar to purposeful play in a few aspects. Authentic contexts were present as the experimenter planned to teach the concept of shapes to the children in the guided play using simple objects, and knowledge about shapes can be used in children's everyday lives. In addition, the guided play was planned to be enjoyable for the children by including a story about finding out the secrets about shapes. Other studies which used *guided play* may fulfill other characteristics apart from the ones that we see in the above example.

In sum, although the term "purposeful play" as defined in Fleer (2013) is not commonly discussed in the literature, we can see some similar characteristics between *purposeful play* and other play-based pedagogies. These examples demonstrated how Fleer's (2013) five characteristics of purposeful play could be implemented.

In our study, we attempted to integrate all five characteristics and to provide an additional example of how purposeful play as defined in Fleer (2013) can be implemented in a preschool setting. The data are presented in the form of narrative excerpts to provide a vicarious experience of a group of preschool children (aged 6) learning about ways to categorize different types of leaves through purposeful play at the Singapore Botanic Gardens. We discuss the affordances of purposeful play in this naturalistic learning context as illuminated through the teacher-student and student-student social interactions. Through this work, we want to demonstrate how purposeful play, when properly planned and capitalized on, could contribute to children's science experiential learning and understanding.

Research Context

Preschool Education in Singapore

As mentioned earlier, science is formally taught to the children at Grade 3 when they are 9 years old. Prior to this, children may have exposure to science through informal experiential learning in preschools, but the emphasis is not on science content knowledge. The opportunities they have to learn science are dependent on the curricula designed by the kindergartens or childcare centers that they attend, which are diverse. Some of them may even have informal science learning experiences provided by their parents.

Children in Singapore attend classes at the Nursery, Kindergarten 1, and Kindergarten 2 levels at ages 3–4, 5, and 6, respectively (ECDA 2015; Skoolopedia 2015). More than 99% of Grade 1 students (aged 7) have attended at least 1 year of preschool. Preschool centers include child/infant care centers and kindergartens. In 2015, there are 292 infant care centers, 1196 childcare centers, and 499 kindergartens. Out of the 499 kindergartens, 10 are MOE kindergartens, more than 200 kindergartens and childcare centers are operated by the *People's Action Party Community Foundation* (PCF, a charitable foundation set up by Singapore's ruling party), and the rest are run by either private commercial or not-for-profit organizations. Kindergartens provide a 3-year education program, where students attend at least 3–4 h of lessons per day for 5 days a week. All the MOE kindergartens adopt a common curriculum guided by the *Framework*, while the PAPCF kindergartens develop their own curricula and lesson materials. Other kindergartens may take reference from the principles of the *Framework* or other philosophies (e.g., Montessori, Regio-Emilia, Waldorf Steiner) and methods (e.g., play based, multiple intelligences, whole brain learning).

Participants

The participants of this study were 6 years old Kindergarten 2 children from a kindergarten located at the void deck of a public residential block in the southwestern part of Singapore. A total of 17 children from this kindergarten took part in the study. The children were from a mixture of above average and average socioeconomic status backgrounds. They were divided into three groups, with each group being led by one researcher. This paper focuses on a group of five children led by one of the researchers. Pseudonyms were used for the children who participated in this study to ensure anonymity.

Activity Conducted

As mentioned earlier, the study was conducted at the Singapore Botanic Gardens. Since it was the first visit to the botanic gardens for most of the children, the researchers briefed the children about the site and the ground rules before starting the activity. The researcher for the group discussed in this study began the activity by challenging the children to pick up as many different leaves as they could find on the ground while they walked through the gardens, with the goal of having them categorize the leaves later. The children took up the challenge, fearlessly roaming through the grounds possibly inhabited by various insects and lizards. The children ran to deposit the leaves in a container carried by the researcher. Along the way, the children saw squirrels, dogs, flowers, fruits, insects, mushrooms, and seeds. After about 45 min of walking and gathering of leaves, the group settled down in an open field, where the researcher got the children to place their collected leaves onto a picnic sheet. In what follows, we describe significant episodes and discuss the affordances of purposeful play for the children.

Methods

Data Collection

The activity was video and audio recorded by research assistants who followed the group of five children and the researcher. The audio recording was merged with the video recording and transcribed.

Data Analysis

The transcribed video was analyzed using the software HyperRESEARCH™. First, one researcher watched the video several times and coded relevant episodes that illustrated the affordances of purposeful play. The same procedure was repeated by another researcher who independently coded the video. Then, the two researchers discussed and agreed on the set of coded episodes that captured evidences of affordances of purposeful play. After a consensus was reached, the first researcher analyzed the coded episodes by identifying emergent codes that described the affordances. The process was repeated by the second researcher who used the same set of codes for analysis as no additional codes were identified in the emergent coding process. Any discrepancy in the coding was discussed until complete consistency was attained.

Findings and Discussion

The activity fulfilled the characteristics of purposeful play as it was conducted in an authentic context where the resource for learning was naturally found. The activity allowed for active learning and risk-taking as the children competed to find the most unusual leaf as they wandered into unknown grounds only to soon realize that there were insects which could bite them. They found the activity enjoyable as they were actively participating in the leaf collection. Finally, they also used their imagination and creativity to describe what they saw around the Singapore Botanic Gardens. For example, they described the huge buttress roots of the kapok tree, which were bigger than them, as "dinosaur legs" and the huge mushrooms as "towers."

In the following paragraphs, we present the excerpts of episodes occurring after the children were gathered to categorize the leaves and illustrate the affordances of this activity that incorporated elements of purposeful play. In the first episode, the children sorted the leaves according to colors, and in the second, the researcher attempted to draw the children's attention to the unique features of some leaves and introduced them to the concept of texture.

Excerpt 9.1 Sorting Leaves According to Colors

Devi:	Where's the green [stack]? This one is to be there! I'm going to put this one.
Adrian:	What? Are you sure that goes in here?
Devi:	Yay, I got plenty. Everything is same as here. This is put here.
[The children gathered around the researcher who asked the children about what they had been doing.]	
Vanessa:	[I've put these together] because they are leaves.
Researcher:	But these are also leaves right [pointing to the leaves placed on another tray]? So why do all these come together?
Vanessa:	Because they are the same.
Researcher:	Same in what ways?
Devi:	This [pointing to a tray of leaves] is brown.
[The researcher turned her attention to David who was quiet and looking elsewhere.]	
Researcher:	David, why do you put these [leaves] together?
David:	All brown.
Researcher:	Are they all brown? Is this [picking up a leaf] brown?
David:	No.
Researcher:	No? So where should this be?
David:	Here [he moves the leaf to another tray].
Researcher:	Here? A bit dark. Okay.
Adrian:	I put this one [leaf] here and this one here.
David:	This one must be here, then this one here.
Adrian:	No!

In this excerpt, we observed rich dialogue between the children and between the researcher and the children. The dialogue illuminated the children's different interpretations of the colors of leaves, especially because they were in different shades of green, brown, and yellow (see Fig. 9.1). The ambiguity of the colors of the different types of leaves opened up opportunities for the children to have a conversation about the sorting of leaves—they questioned one another about their decisions and voiced their disagreement with one another. As opposed to a planned lesson where teachers bring in prescribed materials for children to categorize, the children were immersed in the diversity of nature.

In the next excerpt, the researcher tried to have the children pay attention to the unique or different features of leaves even as they were categorized into the same

Fig. 9.1 Children sorting the leaves according to colors. The group of leaves at the top, middle, and bottom was categorized as brown, a mixture of green and yellow, and green, respectively

group. This was done with the aim of hoping that the children would subsequently identify other ways of categorizing the leaves.

Excerpt 9.2 Identifying Different Features of Leaves

Researcher:	Just now Adrian made a very good observation. Do you see this [referring to the main vein running through the middle of the leaf]? Look at this one [holding up another leaf]. Where is it?
Daniel:	Only at the side.
	[…]
Researcher:	Okay, I also want you to touch the leaves. Touch it, touch this one. How does it feel?
Devi:	Hot.
Researcher:	Anything else?
Adrian:	It got lines.
Researcher:	How does it feel?
Adrian:	Got lines. This one still got lines.
	[…]
Adrian:	This one is more smoother and this one is more hotter.
	[…]
Researcher:	What’s the opposite of smooth?
Vanessa:	Rough.
Researcher:	Yah, that’s right. This is rough. Can you see that this is waxy? This is waxy surface. Waterproof, okay?

Fig. 9.2 The children put all the leaves into one pile and recategorized them. This time, it was according to the texture of the leaves. In this picture, a boy was seen picking up a leaf to feel it before putting it into one of the two new piles of leaves

Earlier, Adrian had noticed that one of the leaves had a main vein that did not run through the middle of the leaf. He shared this unexpected observation with the researcher, who brought it to the attention of the other children. In moving away from the categories of leaves to unique features of individual leaves, the researcher encouraged the children to describe the texture after feeling them. This was an opportunity for her to introduce new vocabulary terms (e.g., waxy, waterproof) and antonyms (e.g., smooth versus rough).

Following the above dialogue in Excerpt 9.2, the researcher went on to ask the children about alternative ways of categorizing the leaves. Vanessa suggested categorizing them according to "how it feels." The researcher took her suggestion and told all the children to do that (see Fig. 9.2). In order to categorize the leaves successfully according to whether they are rough or smooth, the children picked up every leaf to feel the texture. In the process, Adrian picked up a leaf, which was infected and asked, "Oh no, how come some have bumps?" He described the leaf as "bumpy" and questioned why it was the case. The researcher suggested that it could have a disease. This activity allowed children to see that there are many ways to categorize objects and extend the learning of the lesson beyond what was planned.

Implications

The learning objectives as suggested in the *Framework* were fulfilled by this purposeful play activity. In this purposeful play activity, we encouraged the children to observe and be aware of what was happening around them. This builds on their natural disposition of being curious and helps to further develop their interest and disposition toward observing the world around them. Through the activity, the children were seen to gain some knowledge of the world around them, such as leaves can be in different shades of colors, shapes, and sizes, and have different texture. In addition, the activity also served to develop and reinforce various science process skills of the children, including categorization, observation, and communication. Furthermore, as purposeful play involved active participation from the children, it is likely to help the children develop a positive attitude toward the world they live in. All these were part of the learning goals, key knowledge, skills, and dispositions as listed in the *Framework* for the *Discovery of the World*.

Three affordances of purposeful play can be identified in this study. First, purposeful play affords children a near experience of learning about the nature of science and what scientists do. We acknowledge that such experiences are not very similar to what real scientists do and that it would be unrealistic to expect children to acquire in-depth scientific knowledge and practices through this activity alone. However, we observed that this activity had provided an authentic experience for the children to engage in some form of practice of science. Each of the participants brought up their unique observations, and the researcher aided in the process of the sharing of ideas. The children collaborated to complete the task of sorting the different types of leaves although they may not always agree with one another. Such disagreements allowed them to discuss and share their ideas. The authentic context affords children a repertoire of resources that were less predictable and static, hence allowing them to have conversations and negotiations with one another to reach an agreement. As such, the children were indirectly experiencing what some scientists (e.g., biologists) do when they work in natural environments as opposed to working in man-made environments (e.g., laboratory). In the process, they learned that some scientific ideas are based on consensus building (Abd-El-Khalick 2012; Kuhn 1996). Such interactions can help them in refining their science process skills, such as that of communicating their ideas.

Second, purposeful play affords a constructivist platform to learning that actively engages children as learners in the process (Driver and Easley 1978; Duit and Treagust 1998). During the activity, we saw the children actively participating in categorizing or recategorizing the leaves. As they walked through the botanic gardens, the children focused not only on the leaves but also other things such as the roots and fruits of the trees, flowers, insects, and animals in the surroundings and developed interesting ways to describe what they saw using their prior knowledge or personal experience. As such, the children were actively involved in the task and hence their own learning. It is with much anticipation that after this activity, the children would be more aware of their surroundings and apply the same skills in their lives (e.g., sorting out objects at home) and the learning of science (e.g., sorting objects into living and nonliving things).

Third, the authenticity of the context offered diversity, which even the researchers had not expected to find. As an example, through interacting with the leaves, Adrian brought up the observation of the vein running through the center of the leaf, which is an idea that the researchers did not plan to emphasize as part of the lesson. In addition, by allowing children to explore independently during their learning experiences, it also affords more learning opportunities for them. For instance, while picking up the leaves, the children picked up a diseased leaf. This affords an enhanced learning experience for the young learners, as opposed to a planned lesson where teachers bring in prescribed materials which will often be limited to the ideas and concepts that the teachers intended to teach the children. The authenticity of the learning environment opened up opportunities for new discoveries and imaginative approaches to completing the same task.

Conclusion

Our chapter presents an example of how purposeful play can be used to help young children discover about leaves. Our activity fulfilled the learning goals as set out in the *Framework* and also provided affordances to enhance the learning experience of young children. Purposeful play can also be used to introduce other basic science ideas to young children. It is important that these science ideas are relevant to the young children's everyday lives, such that each of the participants is able to bring in their own personal experience to enrich their learning experiences. Future studies may investigate how purposeful play can be used in other activities and examine the ideas that young children share with one another during purposeful play. Such studies would be useful in providing information to teachers or caretakers of young children on how to better design learning activities for young children using the principles of purposeful play.

References

Abd-El-Khalick F (2012) Nature of science in science education: toward a coherent framework for synergistic research and development. In: Fraser BJ, Tobin K, McRobbie C (eds) Second international handbook of science education, vol 2. Springer, Dordrecht, pp 1041–1060

Cutter-Mackenzie A, Edwards S (2013) Toward a model for early childhood environmental education: foregrounding, developing, and connecting knowledge through play-based learning. J Environ Educ 44:195–213

Department of Education, Employment and Workplace Relations (DEEWR) (2009) Belonging, being and becoming: the early years learning framework for Australia. Australian Government DEEWR for the Council of Australian Governments, Canberra

Driver R, Easley J (1978) Pupils and paradigms: a review of literature related to concept development in adolescent science students. Stud Sci Educ 5:61–84

Duit R, Treagust D (1998) Learning in science—from behaviourism towards constructivism and beyond. In: Fraser BJ, Tobin K (eds) International handbook of science education. Kluwer Academic Publishers, Dordrecht, pp 3–25

Early Childhood Development Agency (2015) A good start for every child. Retrieved on November 11, 2015, from https://www.ecda.gov.sg/pages/default.aspx

Fisher KR, Hirsh-Pasek K, Newcombe N, Golinkoff RM (2013) Taking shape: supporting preschoolers' acquisition of geometric knowledge through guided play. Child Dev 84:1872–1878

Fleer M (2013) Play in the early years. Cambridge University Press, New York

Fleer M, Hoban G (2012) Using 'Slowmation' for intentional teaching in early childhood centres: possibilities and imaginings. Aust J Early Child 37:61–70

Kuhn T (1996) The structure of scientific revolution, 3rd edn. The University of Chicago Press Ltd., Chicago

Ministry of Education, Singapore (2012) Nurturing early learners: a curriculum framework for kindergartens in Singapore. Retrieved on January 15, 2016, from http://www.moe.gov.sg/education/preschool/files/kindergarten-curriculum-framework.pdf

Osborne J (2013) Current trends in Science Education: the new PISA assessment framework for 2015 [PDF document]. Retrieved from https://sites.google.com/site/aset2013en/keynote-and-invited-speakers

Skoolopedia (2015) The preschool landscape in Singapore. Retrieved on January 15, 2016, from http://skoolopedia.com/preschool-singapore-2015-infographic/

Weisberg DS, Hirsh-Pasek K, Golinkoff RM (2013) Guided play: where curricular goals meet a playful pedagogy. Mind Brain Educ 7:104–112

Part III
Teacher Professional Development

Chapter 10
Changing Practice: The Impact of Research

Kim Chwee Daniel Tan and John K. Gilbert

Abstract One of the aims of science education research is to produce insights into improving the teaching and learning of science in schools. Unfortunately, many teachers continue to teach in the classroom as if no research has been done into the teaching and learning of their subjects. This can be because teachers are generally unaware of relevant work available and that few researchers are willing to translate research findings into resources which teachers can easily understand and use in class. A survey study which examined the impact of educational research on Singapore middle and high school chemistry teachers' instructional and curricular practices was conducted using semi-structured interviews from 2011 to 2013. This paper reports the findings of the study related to the factors which facilitated or impeded changes in the teachers' existing practices; the findings revealed that these were related to students, teachers, school, the Ministry of Education, time, educational research and teacher professional development. The paper also discusses the sources of information that the teachers used to guide them in making changes or adopting new practices; these included colleagues, teacher educators, electronic resources, conferences and professional development courses and educational research. This study can inform researchers of the issues that are important to teachers and ways of working with them to address these issues.

Introduction

Science education research needs to produce insights to inform the teaching and learning of science in the classroom and policy decisions on science education issues (Millar et al. 2006; Treagust 1995); it can challenge practices which are ineffective or dubious, endorse and provide support to those which are sound and effectual and evaluate innovations to be implemented in the classrooms (Millar et al. 2006). However, researchers seem to have little understanding of the needs of

---

K.C.D. Tan (✉)
National Institute of Education, Nanyang Technological University, Singapore
e-mail: daniel.tan@nie.edu.sg

J.K. Gilbert
The University of Reading, Reading, UK

J. Yeo et al. (eds.), *Science Education Research and Practice in Asia-Pacific and Beyond*, DOI 10.1007/978-981-10-5149-4_10

policymakers and practitioners as studies have shown that policymakers and practitioners have difficulty finding research that is relevant for their immediate needs (Edwards et al. 2007; Nutley et al. 2002; Tseng 2008). One reason could be that research is generally researcher-driven than user-driven leading to the paucity of what policymakers and practitioners would consider as relevant research which could inform their work. Nelson et al. (2009) reported that the policymakers and practitioners in their study believed that "there is a gulf between research design and real-world practice, and that research findings have limited applicability to their local contexts" (p. 50). They also had difficulty accessing, reading, interpreting and applying education research (Nelson et al. 2009; Ratcliffe et al. 2004; Walter et al. 2004). Thus, understanding how, when and why research is used (or not used) by practitioners and policymakers is important to determine the interaction between research, practice and policy, as well as to increase the utilisation and impact of research (Davies and Nutley 2008; Tseng 2010, 2012).

Purpose of the Study

A survey study which examined the impact of educational research on Singapore middle and high school chemistry teachers' instructional and curricular practices was conducted from 2011 to 2013 (Tan and Gilbert 2014). This chapter reports the findings of the study related to the factors which encouraged chemistry teachers to change their chemistry curriculum or the way they taught chemistry, and the factors which constrained changes. It also seeks to determine the sources of information which helped them to make the changes or adopt new practices. The research questions which guided the study were:

1. What are the factors which facilitated or impeded changes in the chemistry teachers' existing practices?
2. What are the sources of information that teachers use to guide them in making changes to their existing practices or adopting new ones?

Method

A survey study (Gall et al. 2007) was utilised to obtain information on the factors which facilitated or impeded changes in the chemistry teachers' existing practices, and the resources that they used or people that they approached to help them in making the changes in their existing practice. The study received ethics approval from first-named author's institution.

A combination of criterion-based, convenience and network sampling (Merriam 2009) was used to select the teachers for the study. The sample consisted of 18 female teachers (62%) and 11 male teachers (38%) with different years of teaching experience from a mix of secondary (years 7–10), pre-university (years 11 and 12) and integrated programme (years 7–12 or years 9–12) schools as well as those working in the Singapore Ministry of Education and a teacher education institution.

Semi-structured interviews were employed, and in cases where the teacher had consented to participate in the study but did not wish to be interviewed, he/she would answer the questions in the interview protocol as if he/she were answering an open-ended survey questionnaire and email his/her responses to the researcher. The questions in the interview protocol which are relevant to this chapter are:

1. What are the factors that encouraged you to change your chemistry curriculum or scheme of work, or the way you teach chemistry?
2. We have talked about factors which facilitate changes, so let's talk about factors which impede or constrain changes.
3. What sources of information do you use most often to help you make changes or adopt new practices?

All interviews were audio-recorded with the permission of the teachers and transcribed verbatim. The interview and written data were analysed to identify recurring "themes supported by the data from which they were derived" (Merriam 2009, p. 23). Findings from previous studies (Nelson et al. 2009; Ratcliffe et al. 2004) suggested several useful themes to code and interpret the data. Such themes include 'time constraints' and 'learning from colleagues'. Other themes were derived through open coding. As the analysis of the interview transcripts and written responses progressed, analytical coding was utilised to combine similar codes, while others were further subdivided or elaborated where necessary. Previously analysed data were revisited and recoded where applicable, and the frequencies of occurrences of the teachers' responses under each theme were tallied. Finally, inferences on chemistry teachers' instructional and curricular practices were made based on the analysis of data.

Results

As the number of teachers involved in the study was small, the responses of the teachers to the interview questions were collated and analysed as a whole group. Excerpts of the interviews used to illustrate the findings were lightly edited, where necessary, to improve their readability. Only factors mentioned by three (10%) or more teachers are highlighted.

Table 10.1 Factors related to students that facilitated changes

	Understanding of concepts	Engagement during lessons
No. of teachers	14	8

Factors That Facilitated Changes

Teachers mentioned factors such as those related to students, teachers, schools, research and the Ministry of Education facilitated changes in their practice.

Factors Related to Students

The factors related to students mentioned by teachers which facilitated changes in their practice were students' understanding of concepts and engagement during lessons (see Table 10.1).

The teachers explored alternative ways of teaching when they found that students did not seem to understand the concepts taught. Teacher T21 stated that he regularly reflected on his teaching and how he could deepen his students' understanding of the concepts, while Teacher T10 would respond to her students' feedback on their learning difficulties:

T10 …I feel that I need to do it differently because…my students…because it doesn't work so well any more…if my students are having difficulty…and when they tell me certain things…I will want to think of a way to change…so if I know that…through the interaction with students like they tell me that this one doesn't work…or they tell me that this work…so…it will help me in that way.

Teachers also wanted to engage students during lessons, so they would think of ways to make their lessons interesting and relevant. Teacher T13 stated that she would change her way of teaching for "topics which are harder or seem boring to the students" by "using videos, showing demonstration, having more group activities or getting students to do more hands on so as to engage the students better and help them understand the concept better too". Teacher T12, as illustrated below, would link concepts to relevant everyday life examples to motivate students to help them understand the concepts better as well as make chemistry more meaningful to them.

T12 …and then when we talk about carbon monoxide poisoning, I think our kids living in Singapore are…it's pretty new…they don't face the problem like in… like when you're living in US, or in cold countries, where you do get quite a big…percentage of…people die due to carbon monoxide poisoning in winter time…so when I brought in video and showed them carbon monoxide poisoning in the home, they were really very surprised…so I feel there is a need to really go beyond textbook to link them to what is around them…so I feel that will make chemistry more meaningful…it's not something they feel they've learnt in the text but they cannot connect to it in their own life.

Table 10.2 Factors related to teachers that facilitated changes

	Teacher characteristics	Inputs from peers
No. of teachers	4	5

Table 10.3 Factors related to school that facilitated changes

	Support for initiatives	School directions
No. of teachers	4	10

Factors Related to Teachers

The factors related to teachers which facilitated changes in curriculum and/or instruction included teacher characteristics and inputs from peers (see Table 10.2).

Teachers need to have to desire and willingness to change as well as have the expertise to effect the changes. Teacher T12 mentioned that she had the desire to change and she took small steps, trying out new ways of teaching one topic at a time, to overcome inertia to change and time constraints. On the other hand, Teacher T23 stressed the importance of increasing the expertise of teachers to help them implement new initiatives.

T23 Ok…I think we're talking about…let's say for example…let's say the last…two to three years ago we did IBL [inquiry-based learning] for example…I think we never really started on it until the HOD [Head of Department] brought in an expert to teach the whole department…so in terms of expertise we're talking about something like that…

Learning from their peers and collaborating with peers are also important for teachers to help them effect changes. Teacher T19 said that he observed his colleague using Twitter Deck to allow students to twit their answers or comments during lessons and that pushed him to "rethink and relook" the way he taught and to explore other possibilities. Teacher T10 was grateful that a few of her colleagues shared her passion in improving practice and collaborated with her to introduce new ideas in the classroom.

T10 …I think my colleagues also…if they are not so cooperative, they are not so open to new ideas…and if I were to do it myself, I think I…wouldn't have that kind of courage or I'll…I would have to take a long time to be sure that…it really works before I try…because when we think of something then all of us will try then we come back and we…discuss…so it's…more encouraging….

Factors Related to School

School support for initiatives and the school's directions played essential roles in facilitating changes to curriculum and instruction (see Table 10.3).

Table 10.4 Factors related to educational research and professional development courses that facilitated changes

	Suggestions for teaching/learning from research	Learning from conferences/workshops/in-service courses
No. of teachers	6	5

Teacher T24's school was involved in a national education project in transforming teaching and learning in the classroom. The project was successful because the school leaders provided much support for the team involved which included scheduled time for team meetings, workshops by experts, special timetable for classes involved and offloading (teaching and admin work) for the teachers involved.

The directions or goals of the school also influence changes in curriculum and instruction as teachers have to work with these directions or goals in mind or the school may exert pressure on the teachers to change accordingly.

T22 Perhaps the direction from the management…like…what they want to emphasize on…then you will tend to…gear…not really geared but you tend to put in things or activities that…will allow students to move in that direction, like… inquiry learning is one…like here…lower years should let students go through the inquiry process…then subconsciously when you plan your activities, you will think in terms of that direction…so it's…also a direction set by the school…the department…

Factors Related to Education Research and Professional Development

Several teachers said that educational research and professional development courses, for example, conferences, workshops and in-service courses, provided ideas or support for them to change their practices (see Table 10.4).

Teacher T15 mentioned that she would read research articles to find out what others had done and whether if she could replicate what they did with her students, while Teacher 31 valued conferences or other sharing platforms as she could learn best practices by listening to the presenters, asking questions and approaching them for help.

T15 To make changes…factors…let's say you have research articles…I would of course, look at what people would have done and maybe I can replicate what they have done in my classrooms…I mean that is a very good backup you see…rather than I just try out you know without any…basis…cause I know even in other departments, they are also doing readings, on their own to back up their new approach.

T31 I usually would…like conferences or cluster sharing or school sharing…because I can then choose to see what they are sharing and then what they have done, whether it's appropriate…they are there, I can question, I can ask, and should I need help, I can then…go and approach them…that

Table 10.5 Factors related to the Ministry of Education that facilitated changes

	Changes in curriculum/ assessment	Ministry initiatives
No. of teachers	8	11

would be one of the easiest way to gather…practices, best practices from other people.

Factors Related to the Ministry of Education

Revision of the curriculum, changes in assessment or initiatives launched by the Ministry of Education, had an impact on practices in school (see Table 10.5).

Teacher T7 stated that he modified his teaching for "(b)etter alignment to current method of assessment, and style of questions asked in 'A' Levels" and Teacher T25 "had to improve the quality of the questions that we expose students to in normal tutorials" in order to help students answer higher-order thinking questions. Similarly, Teachers T27 had to focus more on thinking skills in his lessons in response to the greater emphasis on thinking questions in the national examinations.

One of the recent initiatives of the Ministry of Education is to enhance students' "life-ready competencies like creativity, innovation, cross-cultural understanding and resilience" (Ministry of Education 2010). Thus, Teacher T12 explained that teachers "need to move… with the direction that the MOE has set".

T12 I think…it would be like trying to make learning meaningful for the students… or teach them skills that will help them…it's like…what do you call…take them into the twenty-first century…and I find that as a teacher, I need to move…with the direction that the MOE has set…and I also see that…we…are past a stage where we…are textbook bound…we must go beyond that…so I feel that in a lot of ways, I need to change the way I teach…although there is a need to do a lot of content required for the exam but it would also be nice to be able to enrich the students…so that they are able to connect what they have learnt and find meaning and a bigger purpose in the world they are living in.

Teachers in Singapore have been using information and communication technologies (ICT) to help students learn science by helping them to experience and visualise phenomena, access developments in science and engage in scientific inquiry (Tan and Koh 2008). The Ministry of Education, recognising the potential of ICT and collaborative learning as well as innovative practices in some schools, strongly encourages all schools to infuse more ICT and collaborative learning in their programmes; this is reflected in the response of Teacher T19.

T19 Ok…(at the) department level…because recently there's this BY(i)TES [Baseline ICT Standards] thing…so require about 35% of curriculum…minimum that's required to be either collaborative learning or student-directed learning…so, with that we need to revamp…all our 3 levels worth of SOWs and our…curriculum, in that sense…

Factors That Impede or Constrain Change

The factors which facilitated change as mentioned in the previous section, for example, factors related to student, teacher and school, could also impede or constrain change. The limited time that the teacher has for classroom teaching and the time required to make instructional and curricular changes also do not encourage them to make changes in their practice.

Factors Related to Students

Ten teachers indicated that their students played a part in constraining changes to the way they teach. There was a tendency to stick to tried-and-tested methods, didactic teaching or following the syllabus closely when teaching weaker students as teachers feared the students could have learning difficulties if they employed new pedagogies or taught more than what was required in the syllabus. The interview excerpt with Teacher T6 illustrates this tendency:

> T6 …with the weaker batch students…so we have to…but we still stick to the… SIOs [specific instructional objectives] but as you know for JC it's usually… we tend to teach beyond the syllabus…some areas in fact could be quite substantially…we find that this is not…viable for the weaker students…because those things that are not needed by them…if you teach…they tend to be causing more confusion among students so we have to trim it down and stick very closely to the syllabus requirement…

Teacher T6 explained that several of his junior college students wanted to be taught the way they were taught in secondary school, that is, through drill and practice and be "provided with 'guaranteed to score' model answers" which would help them do well in the national examinations. Teacher T11 also commented that students brought "habits that they have previously cultivated, such as heavy reliance on spoon-feeding of knowledge by their teachers and memorising rather than understanding of content" from secondary school to junior college. Their resistance to change was to be expected "especially if their strategies brought them reasonable success in their academics prior to JC". Unfortunately, the junior college national examinations require more than "superficial understanding of the subject", so Teacher T11 cautioned that students "need to rethink their ways of learning".

Factors Related to Teachers

Table 10.6 shows the factors related to teachers which impeded or constrained changes.

Teachers might also not want to or be ready to change their ways of teaching. Teacher T6 believed that teachers "must feel confident that such changes are viable in their opinion" and would weigh the cost and benefit of introducing the changes.

Table 10.6 Factors related to teachers that impeded changes

	Teacher characteristics	Teachers' assessment concerns
No. of teachers	9	10

So, if teachers were not ready for the changes or not convinced that the changes would be beneficial, then their implementation would be problematic.

T6 I think teacher factor is one very important, because whenever you want to make changes, teachers, first of all must be comfortable with it, especially those pillars…I mean your subject heads…your ST [senior teachers], because they are the one with the most experience…they are the one actually helm the particular subject…so they must feel confident that such changes are viable in their opinion…of course they always measure the changes against their years of experience and try to make a judgement call whether such change is beneficial and weighs against…the effort that needs to be put in to prepare for these changes…so if the teacher is not ready…to push for IT, for example…then you find that it's not that…although we can always specify a certain percentage for our lessons to be IT based whatever…but if the teachers are not comfortable…and not too familiar with the use…you find that you…you may have the percentage on paper, but actually implementation wise, you find that it's…could be quite minimal.

The teachers' assessment concerns are closely related to time constraints as they need to complete the syllabus and prepare students for the examination. These are highlighted by the following excerpt of interview with Teacher T18; she mentioned that she was unlikely to carry out activities which are not in the syllabus, and hence not assessed:

T18 …for example, let's say I find certain experiment interesting like…it can be the old olden type of the…let's say when I teach pH and indicators it can be you can do some fountain experiments…I mean those are good experiments for them to understand pH and changes, colour changes…but in the context of syllabus and time constraint I may not want to do that because it may take up time and after all in that sense, it's not inside the syllabus to know this particular experiment…it's a good to have, it's an add-on…and they're not assessed on this…

Factors Related to School

The directions or goals of the school, lack of support from the school and availability of resources in the school were factors mentioned by teachers which impeded changes (see Table 10.7). Teacher T31 said that she needed to heed directions from her Head of Department or school and "if the school says no, you cannot do, you cannot innovate, everybody must follow". Similarly, Teacher T10 mentioned that if

Table 10.7 Factors related to school that impeded changes

	School directions	Support for initiatives	Availability of resources
No. of teachers	4	4	4

Table 10.8 Factors related to time that impeded changes

	Instructional time	Time to make curricular changes
No. of teachers	11	5

her "school or rather the Principal, the management doesn't really encourage us to…try out new ideas" then she would not want to do so.

The availability of resources determined what was possible to implement in school. Teacher T21 mentioned that his school did not subscribe to an online resource site, so his students were not able to do the online experiments that he wanted them to experience. The lack of laboratory equipment prevented Teacher T25 from introducing organic synthesis practical work to his students, as illustrated below:

T25 …but we must have…the required resources, so…this year for the JC 2 team, they actually wanted students to do organic synthesis, but…even when we wanted to do synthesis in groups, let's say our students work in groups of 3 or 4, we couldn't do it, because for the setup, we actually needed one of the adapter, to connect the round bottom flask to the…reflux column, and, we had to go and source around, go and beg from other JCs; it really constrains us in a way, so, there were some teachers who actually found that, if it's so difficult, then don't do it…

Factors Related to Time

The limited time for classroom teaching that the teacher had and the time required to make instructional and curricular changes hindered their efforts to make changes to their practice (see Table 10.8).

Teacher T7 stated that he could not scale up an innovative way of teaching in his junior college, even though the feedback on the trial seminar style teaching he experimented with was good, because it took too much curriculum time. Teacher T22 also complained that he had to continue teacher-centred teaching because of the need to complete the syllabus in time for the examinations.

Teachers may also have little time to think about how to improve practice, or to develop or source for new material and strategies. Teacher T15 mentioned that when her teaching was over for the day, she had to attend meetings in the afternoons, so "we really have very little time left to, you know…to prepare our lessons, in that sense, like having very innovative kind of teaching". Teacher T18 also said that administrative work and co-curricular activities (CCA) took up much time such that she could do little reflection on her teaching and lesson planning.

Table 10.9 Sources of information for teachers

	Colleagues	Electronic resources	Conferences/workshops/ courses	Educational research
No. of teachers	25	15	14	20

Sources of Information for Teachers

The people that teachers approached and resources that teachers used to help them make changes or adopt new practices are summarised in Table 10.9.

Colleagues

Colleagues, especially those who are more experienced or senior, are commonly relied upon for advice or ideas. Teacher T7 stated that observing the lessons of more senior teachers would help others "gain a different perspective" or "compensate for potential blind spots". In addition to peer observations, Teacher T13 "would look for other chemistry teachers in my school, share with them my ideas or the difficulties that I faced". Similar comments were given by Teacher T29:

> T29 I would discuss with my fellow chemistry colleagues, and of course those with more experience…they are the senior teachers, they will be my mentor…I will usually go to them if I need help for practicals, if I want to teach, if I teach something to my students and they don't seem to understand it even after I have been teaching them for one period…then I'd go back to them and ask them how do I teach this in an easier way for my students to understand…then they will help me with that.

Teachers also worked in teams to discuss ideas and develop lessons as illustrated by the interview excerpt with Teacher T23:

> T23 …we used to…we…this two period let's call it white space, the two periods that are allocated per week that the Chemistry teachers actually meet…so whoever who learns anything from let's say meeting, workshop whatever during that period normally we share, we discuss and talk about it and then… anything that we think is useful and all kinds of thing we will ask the person to actually elaborate further and then see how we can incorporate it into actually any of our lessons and all…which is actually quite good, everybody learns…it's a weekly thing…we meet.

Electronic Resources

Teachers normally search the Internet for resources such as simulations, animations and videos to include in their lessons or even lesson plans. This can be seen from the excerpts of interviews with Teachers T21 and T25.

T21 …as for resources wise…I also…turn to the Internet…when I Google like certain chapters or things like that…there are actually some websites that provide lesson plans, and, like applets and things to teach that thing…so…I will filter through the Internet to see what are the resources that are available.

T25 We do try to find online for sort of the ideas…because typically when we go online we'd be looking for videos, we'll be looking for animations…so all these are typically along the line of trying to engage students, attract their attention…

However, Teachers T11 stated that she did not have access to many journal articles which appeared in the internet search results and T20 complained about the cost of buying or downloading such articles.

Conferences/Workshops/Courses

Conferences and professional development workshops or courses are avenues for teacher learning, building expertise and making contacts with people who can help teachers implement new pedagogies back in their schools as illustrated by the following excerpts of interviews:

T5 The other source is of course sometimes we send teachers out for workshops… that is when they learn…new pedagogies…for example, this year we intend to do a modelling approach, so we sent our teachers for workshops on that to build their capacity…

T6 …let's say you attend a conference, or a seminar…you run into somebody who did some study…regarding, say, particular topic…that…you found that there's some highly positive result…outcomes from the their intervention because they do the things a certain way…that's one way…you can contact with the particular…PI [principal investigator]…and then you talk to them to see whether we can actually implement that in school…in fact I think, again from observation at HQ (Ministry of Education), it's quite common nowadays for teachers who attend conferences actually to get themselves linked up with the…researchers…and then they start implementing these in school.

Educational Research

Twenty teachers mentioned that they regarded educational research as a source of information on how to teach more effectively and how to help students learn more meaningfully. Teacher T7 mentioned that he consulted "educational research for alternative conceptions, common issues, different modes/ways of teaching that topic" and Teacher T20 would "try to read, journals, articles, just to see what the recent trends are, and be aware of the challenges that people experienced". Teacher T25 referred to research literature to identify frameworks and tools which could be used to facilitate inquiry in class:

T25 …usually we try to see whether something has been done first…for example, we try to embark on a science inquiry curriculum, because there was the belief that…inquiry will help students to become more independent learners, and it will also…it's also more in line with the spirit of science; so before we embark on this curriculum, we actually had to do a lot of reading up on what is inquiry, what are the frameworks or models of inquiry that are available, which is the one that best suits our needs, and then…what are the…some of the tools that you can use to try and facilitate inquiry.

Discussion

The data seem to suggest that if (a) students are doing well in the examinations or prefer didactic teaching, (b) teachers judge that their students may have learning difficulties if they try something new or teach material outside of the syllabus, (c) teachers are not ready or do not have the expertise to implement the changes and (d) there is a lack of resources or support from school to implement changes or the changes are not in line with the school directions, then there is little incentive for teachers to move away from tried-and-tested methods of teaching. Students who were very focused on examination tend to "add on" to teachers' assessment concerns and inertia to change. As mentioned in the previous section, some students of Teacher T6 just wanted to know how to answer examination questions so that they could do well in the examinations rather than explore and construct their own knowledge. These students were very resistant to any move which depart from teacher-centred teaching and so did not encourage teachers to change their way of teaching.

In addition, teaching tasks (such as completing the syllabus and preparing students for the examinations) and other competing demands (such as meetings, committee work, running co-curricular activities and school events) restrict the time that teachers have to read and think about or introduce new ways of teaching (Walter et al. 2004; Nutley et al. 2009). It is quite likely that a teacher may face multiple factors which dissuade him/her from changing his/her practice; for example, his/her students may have been doing well in the examinations and are not receptive to any change which they feel may affect their chances of success, the lack of time to develop and implement changes, the inaccessibility of research findings and the lack of support from colleagues and the school management.

However, the teachers mentioned that they might consider changing their practice if their students have difficulty in understanding what was taught and/or they wanted students to be more engaged during lessons. In addition, if they were required to implement initiatives of the school or the Ministry of Education, or there were changes in the national curriculum and assessment, the teachers would review their schemes of work and lesson plans to determine how to incorporate the initiatives or changes into their practice. These impetuses to change (Tan and Gilbert 2014) may result in teachers considering educational research to help them make the required changes.

The data also show that the main sources of information for teachers to help them to make changes or adopt new practices are fellow teachers (86%) and this agrees with the finding of Ratcliffe et al. (2004) that "colleagues were seen as the most important source of ideas and guidance" (p. 34). Other sources of information include educational research (69%), the Internet (52%) and professional development courses (48%). Teachers can have access to educational research directly through reading or indirectly through research-informed resources available on the Internet, professional development courses and relevant discussions with fellow teachers. The impact of these sources of information on the teacher's practice may not be great, for example, due to limited contact time, but they do offer opportunities for teachers to get new ideas and instructional material, as well as network with other teachers, teacher educators and researchers (Mamlok-Naaman et al. 2013).

In Singapore, researchers can tap on the value that teachers place on the opinions of, and endorsement by, colleagues (Ratcliffe et al. 2004; Tseng 2010) as well as the importance of social processes in influencing research interpretation and use (Tseng 2008). These social interactions can occur in the various Professional Learning Communities (PLC) in school or in the Chemistry Subject Chapter. The formation of PLCs in schools is strongly encouraged by the Ministry of Education as a means of professional development for teachers (Ministry of Education 2009). Teachers collaborate to conduct action research or lesson studies in these PLCs with the aim of improving teaching and learning in the school, and this will expose them educational research; in addition to conducting studies, teachers would also have to read research articles and books to get ideas to develop their interventions and methods of obtaining data to evaluate the effectiveness of their interventions. When teachers collaborate, they not only support each other but also share the load of developing, implementing, evaluating and revising instructional material and strategies; this helps them to address the constraints of time that a single teacher would face in the process. When the studies are completed, teachers are often supported by their schools to present and share the findings at conferences. Examination of the programme book of the recent International Science Education Conference held in Singapore in December 2014 revealed that Singapore teachers were involved in about 30% of the 228 papers listed in the book. The teacher-generated papers at this conference provides some evidence that teachers are examining the way that they teach and changes in the classroom are being facilitated by collaborative inquiry into their practices. Hopefully these teacher-generated papers presented, and also available in the proceedings, would influence other teachers, likewise, to examine their practices and evaluate how educational research can make an impact in their classrooms.

Subject chapters have been set up by the Ministry of Education to grow communities of practice in which teachers learn from, and collaborate with, each other to raise the standards of teaching and learning of the subject (Academy of Singapore Teachers 2012). All teachers teaching chemistry are members of the Chemistry Subject Chapter, and meetings are generally facilitated by the Chemistry Master Teachers from the Academy of Singapore Teachers, senior school teachers, teacher educators and educational researchers. These facilitators are respected for their professional expertise, so they can be important intermediaries in recommending relevant research, facilitating “productive discussion of research evidence” (Ratcliffe et al. 2004, p. 36) and translating research for use in the local context (Nelson et al. 2009) – these activities can make educational research more accessible and plausible to teachers (Tan and Gilbert 2014), helping teachers to address the lack of expertise and time constraints if they want to explore the use of research to inform their practices. Practice can also inform research as educational researchers can address the issues raised in discussions as well as the difficulties that teachers encounter in implementing research ideas in their own schools (Tseng 2012) in their current or future research endeavours to make their research more fruitful to teachers (Tan and Gilbert 2014), leading to a cyclical use of research (Walter et al. 2004).

Limitations

The small sample sizes of the teachers involved in the study and the non-random sampling of teachers are limitations to the study. Thus, the data obtained are not representative of the chemistry teachers in Singapore schools. The findings of the study are also limited by the nature of the data collected as there was no substantiation of the information given by the teachers, for example, through document analysis and direct observations (Nelson et al. 2009). However, the findings do give an indication on the impact of research on the practices of teachers and can contribute to a follow-up study involving a larger-scale survey of chemistry teachers or even science teachers.

Conclusion

These findings of the study showed that the factors which facilitated or impeded changes in the teachers’ existing practices were related to students, teachers, school, the Ministry of Education, time, educational research and teacher professional development. Teachers will not change their practices unless there are compelling reasons to do. The sources of information that the teachers used to guide them in making changes or adopting new practices included colleagues, electronic resources, conferences and professional development courses and educational research. The Chemistry Subject Chapter of the Academy of Singapore Teachers can be an important intermediary facilitating interactions between teachers and researchers to enhance the impact of research on practice as well as the impact of practice on research.

Acknowledgements The work reported in this paper was supported by research grants (RS 2/11 TKC) from the National Institute of Education, Singapore.

Some of the material in this book chapter is based on a published paper: Tan et al. (2014). Reproduced by the permission of The Royal Society of Chemistry.

References

Academy of Singapore Teachers (2012) Subject chapters. Retrieved from http://www.academyofsingaporeteachers.moe.gov.sg/professional-networks/subject-chapters

Davies H, Nutley S (2008) Learning more about how research-based knowledge gets used: guidance in the development of new empirical research. William T. Grant Foundation, New York

Edwards A, Sebba J, Rickinson M (2007) Working with users: some implications for educational research. Br Educ Res J 33(5):647–661

Gall MD, Gall JP, Borg WR (2007) Educational research: an introduction, 8th edn. Allyn and Bacon, Boston

Mamlok-Naaman R, Rauch F, Markic S, Fernandez C (2013) How to keep myself being a professional chemistry teacher. In: Eilks I, Hofstein A (eds) Teaching chemistry – a studybook: a practical guide and textbook for student teachers, teacher trainees and teachers. Sense, Rotterdam, pp 269–298

Merriam SB (2009) Qualitative research: a guide to design and implementation. Jossey-Bass, San Francisco

Millar R, Leach J, Osborne J, Ratcliffe M (2006) Research and practice in education. In: Millar R, Leach J, Osborne J, Ratcliffe M (eds) Improving subject teaching: lessons from research in science education. Routledge, London, pp 3–23

Ministry of Education (2010) MOE to enhance learning of 21st century competencies and strengthen art, music and physical education [Press Release]. Retrieved 6 June 2014 from http://www.moe.gov.sg/media/press/2010/03/moe-to-enhance-learning-of-21s.php

Ministry of Education Singapore (2009) Teachers – the heart of quality education [Press Release]. Retrieved 18 January 2014 from http://www.moe.gov.sg/media/press/2009/09/teachers-the-heart-of-quality.php

Nelson SR, Leffler JC, Hansen BA (2009) Toward a research agenda for understanding and improving the use of research evidence. Northwest Regional Educational Laboratory, Portland

Nutley S, Davies H, Walter I (2002) Evidence based policy and practice: cross sector lessons from the UK. Research Unit for Research Utilisation, University of St Andrews. Retrieved 4 June 2014 from http://www.kcl.ac.uk/sspp/departments/politicaleconomy/research/cep/pubs/papers/assets/wp9b.pdf

Nutley S, Walter I, Davies HTO (2009) Promoting evidence-based practice: models and mechanisms from cross-sector review. Res Soc Work Pract 19(5):552–559

Ratcliffe M, Bartholomew H, Hames V, Hind A, Leach J, Millar R, Osborne J (2004) Science education practitioners' views of research and its influence on their practice, Evidence-based Practice in Science Education (EPSE) Research Report. University of York, York

Tan KCD, Gilbert JK (2014) Chemistry teaching: impact of research on practice. Chem Educ Res Pract 15(2):207–218

Tan KCD, Koh TS (2008) The use of Web 2.0 technologies in school science. Sch Sci Rev 90(330):113–117

Treagust DF (1995) Diagnostic assessment of students' science knowledge. In: Glynn SM, Duit R (eds) Learning science in the schools: research reforming practice. Lawrence Erlbaum Associates, Mahwah, pp 327–346

Tseng V (2008) Studying the use of research evidence in policy & practice, William T. Grant Foundation 2007 Annual Report. William T. Grant Foundation, New York, pp 12–19

Tseng V (2010) Learning about the use of research to inform evidence-based policy and practice: early lessons and future directions, William T. Grant Foundation 2009 Annual Report. William T. Grant Foundation, New York, pp 12–19

Tseng V (2012) The uses of research in policy and practice. Soc Polic Rep 26(2):3–16

Walter I, Nutley S, Percy-Smith J, McNeish D, Frost S (2004) Improving the use of research in social care, Knowledge Review 7. Social Care Institute for Excellence/Policy Press, London

Chapter 11
Showcasing Singapore Science Teachers' Research

Jennifer Yeo

Abstract To support teachers in Singapore to face up to the demands of a changing landscape in education, teachers have been encouraged to inquire into their teaching practice through teacher-led research. The goal is to generate evidence-based knowledge about their own teaching and students' learning that can be used to inform their curriculum and practices. The success of this initiative is evident in the number of presentations made by school science teachers of their research efforts at the International Science Education Conference 2014. This chapter highlights three studies that illustrate the research conducted by Singapore science teachers and the benefits and the challenges of conducting teacher-led research, as well as the collaboration among science teachers and ministry officers.

Introduction

An increasingly complex educational landscape in the twenty-first century necessitates a much higher level of teaching competencies from teachers. A call from the Prime Minister of Singapore, Mr. Lee Hsien Loong, in his inaugural National Day speech in 2004, for schools to "Teach Less, Learn More" (TLLM) (Lee 2004) shifts the focus for school leaders and teachers to prepare students for life rather than merely teach for examinations and tests (Shanmugaratnam 2004). Teachers will now need to help students take ownership of their own learning, develop their attributes and mindsets for the uncertainty and challenges of life, and develop character and sound values. A one-size-fits-all curriculum will no longer be sufficient; rather a customized curriculum that matches the profile of students in the school to help them excel in what they are good at and to prepare them for the uncertainty of the twenty-first century is needed. In other words, excellence in pedagogy that engages the minds of the students will now be needed. Deeper and richer interactions among teachers and students should also be the norm, and more opportunities for students to learn and develop holistically should be provided.

J. Yeo (✉)
National Institute of Education, Nanyang Technological University, Singapore
e-mail: jennifer.yeo@nie.edu.sg

J. Yeo et al. (eds.), *Science Education Research and Practice in Asia-Pacific and Beyond*, DOI 10.1007/978-981-10-5149-4_11

The TLLM initiative meant that teachers in Singapore have to get out of their comfort zone to find new ways to engage their students and to help them learn not only the content better, but also to develop their skills and attitudes within the disciplines they teach. In the context of school science learning, this meant that science teachers not only need to help students acquire knowledge and understanding of the scientific content, they also need to look at ways to inculcate the scientific skills (e.g., planning, investigation, reasoning, argumentation, problem solving, creativity) and attitudes (e.g., curiosity, interest, integrity, inquiry, and inventiveness). To achieve these goals, the Ministry of Education (MOE), Singapore, has defined the desired outcomes of a twenty-first-century teacher to be an ethical educator, a competent professional, a collaborative learner, a transformational leader, and a community builder (Ministry of Education, n.d.). In this framework, teachers are called to develop excellence in pedagogy and assessment, to take charge of their own professional learning, to collaborate with one another to solve similar problems, to share ideas, and to develop best practices collectively.

To support teachers to meet these challenging outcomes, teachers were encouraged to inquire into their practices through teacher-based research (Shanmugaratnam 2006b). The goal is to generate evidence-based knowledge about their own teaching and students' learning that can be used to inform their curriculum and practices. As well, such professional development approach can further encourage teachers to be role models of a life-long learner, an inquisitive inquirer, and an innovator for their students. Supporting this bottom-up approach to professional development is top-down support from the Ministry of Education. Workshops on practice-based research methodologies such as action research and lesson study are provided to teachers engaged in inquiry into their own pedagogical practices. Teachers form groups such as professional learning circles/teams (PCL/T) to explore different pedagogies and research methodologies to solve pedagogical problems. Time is built into the teachers' timetable to allow the PLC/T a common timeslot to come together to share, discuss, and plan for their inquiry. Supporting the teachers and PLC/Ts are research activists (Shanmugaratnam 2006b) and school staff developers (Shanmugaratnam 2006a). The research activists are teachers appointed by the school to act as a research advocate and to help teachers with issues related to their inquiry. The school staff developers are appointment holders in the school who not only guide the PLC/Ts in their inquiry, they also chart the direction of the school's professional development. Other supports provided include grants for schools to embark on more resource-intensive innovations (e.g., Edulab funds for ICT-based pedagogies) and support from various specialized divisions in the MOE such as the Educational Technology Division, a division that advocates the infusion of ICT into classrooms, and Academy of Singapore Teachers, an outfit that promotes pedagogical innovation.

The fruits of these initiatives were evident in teacher-oriented conferences. In the International Science Education Conference 2014, about 50 paper presentations were from Singapore school teachers. Each presentation bore the testimony of teachers' innovation, the collaborative efforts, and the learning they had derived out of the experience. This chapter aims to highlight some of these presentations and illustrate how these presentations demonstrate the outcomes of teacher-based research as professional development. The affordances that made this achievement possible are also identified.

Teacher-as-Researcher as a Professional Development Approach

The notion of teacher-as-researcher was mooted as early as in the 1950s in the United States, whereby action research was highly promoted. It was then conceived as a scientific method modeled on the experiment to solve educational problems. Associated with Dewey, action research is seen as a way of assessing scientific recommendation of pedagogy being applied in practice whereby the teacher acts as a researcher testing out educational theory.

Similarly, in Britain, the idea of teacher-as-researcher came at a time when there was more emphasis on the process of teaching as a skilled and locally managed activity. It calls for individual teachers to be given more autonomy in curriculum change, emphasizing their role as skilled practitioner who is continually reflecting on his/her practice in terms of ideals and knowledge of local situations and modifying practice in light of the reflections, rather than a technician merely applying scientifically produced curriculum programs. The goals are for teachers to discover how to improve his/her teaching through systematic questioning of one's own teaching as a basis for development, studying one's own teaching, questioning and testing theory in practice, and working collaboratively with others in discussing and giving feedback to one another on their teaching (Stenhouse 1975).

In recent years, other models of teacher-as-researcher have emerged. Examples include lesson study and learning study. Lesson study is a teaching improvement process that originated in Japan, whereby teachers work with one another to discuss learning goals, plan an actual lesson, observe how their ideas are implemented in the classroom, and report on the results (Takahashi and McDougal 2014). Learning study originated in Hong Kong is another professional development model whereby the teacher inquires into his/her teaching. It takes learning as the object of inquiry rather than focus on various aspects of a lesson (e.g., classroom management, teaching strategies, and implementation of a new curriculum).

Common to these various models of teacher-as researcher is the emphasis on empowering teachers to improve their own professionalism through the inquiry process. The goals are to enable teachers to become competent in their professional work, and to become collaborative learners and community builders as they work with one another to solve students' learning problems.

Case Examples of Science Teacher-Led Research

In the following sections, we present three case examples of teacher-as-researchers' work to illustrate the research conducted by Singapore science teachers and the benefits and the challenges of teacher research, as well as to identify affordances that made such efforts possible. These three case examples were sampled from the full papers submitted to the conference proceedings and presented at the conference.

Case Example 1 *An approach to holistic education – cultivating 21st century competencies using team-based learning (TBL) in the teaching of higher 2 (H2) biology by Foo-Lam, Soh, Widodo, Chia, Heng, Nah, Liu, & Toh (2014).*

This case example illustrates the inquiry of a team of biology teachers from a local high school into the adoption of team-based learning (TBL) approach (Parmlee et al. 2012) to achieve the school's mission of developing their students' critical thinking, creative thinking, and caring thinking. Having come across TBL during a workshop, and after subsequent communication and assistance from the workshop presenters, they found it appropriate to meet the demands of their school's mission. The teachers incorporated TBL's three-part process consisting of readiness assurance process (RAP), team application (tAPP) activity , and tutor feedback with their holistic education framework to produce a learning package that puts students in charge of their learning. Collaborative work was emphasized by getting students to build consensus of their answers during pre-lesson assessment and problem solving. Commenting and justifying views and choices to convince others, were also designed into the activities. Throughout, supports in the form of content and process facilitation were provided to help students along in the process of learning.

The teachers monitored students' engagement and learning throughout the process. They found that students' understanding of biological concepts had improved based on their MCQ scores that tested their ability to recall and apply biological content and concepts to problem solving tasks. Through qualitative means such as students' feedback and teachers' observation, they reported that many students had learnt about patience and sensitivity to one another during group work. Students also found collaborative work valuable and the process of learning enriching and interesting. They were also more motivated to take ownership of their learning (such as by doing additional research required to answer the tasks given). Teachers also observed that students' thinking improved over time, and new ideas often emerged from collaborative processes Students ideas were also made more visible during discussion, which allowed teachers to question assumptions and address misconceptions.

Amidst the positive observations, the team also reported challenges faced, especially in the initial few topics. For example, they found tAPP inefficient when students could not agree on a common answer or if questions were too straightforward. Identifying these challenges triggered interventions and new learning to be produced.

The teachers' inquiry into the use of TBL for biology learning had generated a number of new knowledge for them. They learnt about the need to craft challenging and open-ended questions that test fundamental concepts, yet allow for alternative solutions. The teachers also showed cognizance of the advantages of TBL, as well as developed awareness of the challenges. More importantly, through the process of addressing the challenges, they innovated their practices, made evidence-based decisions, and collaboratively transformed themselves to meet the demands of the school's mission to improve the learning of their students.

Case Example 2 *To improve the planning skill in chemistry investigation through Knowledge Building and virtual lab, by Lo, Soh, Chew, Lam, Wan, & Gawade (2014).*

The second case example highlights a collaborative inquiry among teachers from four local secondary schools. This inquiry was funded by the Edulab grant that provides financial support to schools embarking on pedagogical innovations using ICT. Connected by a common interest in the pedagogy of Knowledge Building (KB) (Bereiter et al. 2006) and virtual laboratory, and a common need to develop students practical skills as stipulated in the chemistry syllabus, the teachers from these four schools came together to investigate the effects of virtual laboratory and Knowledge Building on students' planning skills of scientific investigation. The intent was to engage students in dialogic work (Driver et al. 2000) through engagement in Knowledge Building. Students worked on solving a problem by understanding their role in the task, understanding the task, experimenting to test solutions and find evidences to support their claims, consolidating their knowledge through negotiation and justification, and finally reflecting on their theories and applications and sharing their findings with other groups.

The study reported findings from two of the four schools. The research method involved students from each school to be involved as an experimental or control group. Other than the teacher in the control group for one school, the other teachers involved in this study were trained in both Knowledge Building and Knowledge Forum, a online discussion tool. To find out the extent that KB and virtual lab can develop students' skills in designing investigations, data included pre- and post-tests, students' online posts, and surveys on self-directed learning and collaborative learning. Analyses of the KF online posts suggested different patterns of interactions among the students in the two schools. Pre- and post-tests of the students' ability to design experimental tests showed that there was significant improvement in the treatment groups, but not the control groups. A qualitative comparison of the notes posted by the experimental and control groups showed that ideas and discussions were deeper for the experimental groups. However, the teachers also reported that the discussion patterns were different between the two experimental groups. A deeper analysis into the tasks showed a difference in the nature of their tasks. This led teachers to realize that more open-ended tasks could elicit greater diversity of answers, which in turn triggered more views of the posts, and suggestions and build-ons from other groups. Teachers also realized the potential of online discussion boards as they examined the notes produced by the students. Citing an observation of how the reading of others' posts helped a lower-ability student improve his posts, the teachers began to realize the importance of public display of students' ideas in making thinking visible and extending one's capability. Analysis of the self-directed learning and collaborative learning surveys also produced results indicating that students in the experimental groups were more eager to look for information on their own and they collaborated better and learned from one another than the control groups. It was also reported that the teachers found that the animations they used with the tasks for the experimental groups had served as good visual aid to support students.

This case example is a good instance of a collaborative inquiry cutting across different schools. The similar problem faced by the four schools brought them together to collectively work together to address the challenge. The synergy in designing and implementing a similar pedagogy, albeit with differences, brought about different observations which allowed the teachers to rise above from the various experiences to produce new knowledge that allowed them to better understand what works in the pedagogy. In this respect, the Edulab grant had provided the teachers with the financial support to experiment with ICT tools which might cost money and time to implement.

Case Example 3 *A case study on the professional growth of a science teacher in a learning community by Poh, Phua, Aw, & Lin (*2014*).*

This case example illustrates the transformation of a biology teacher in a local secondary school as she collaborated with officers from ETD to redesign the school's biology curriculum with the infusion of ICT practices. The redesigned curriculum was to provide students with opportunities to work together on complex authentic problems and to make their thinking visible through digital artifacts that were created collaboratively.

This collaboration between the teacher and ministry's officers was made possible by the setting up of various learning communities helmed by various divisions in the ministry. The purpose was to overcome the inertia and challenges of inventing and applying educational innovations. Collaborative Science Inquiry Learning Community (CSILC), established by the Educational Technology Division (ETD), was one example. Acting as a catalyst in schools in the harnessing of ICT for teaching and learning, the goal of the CSILC was to engage and collaborate with science teachers to deepen and strengthen the use of ICT in science inquiry activities through professional learning activities such as workshops, networking events, and lesson codesign sessions.

This study focused on the transformation of the teacher in her pedagogical beliefs and her ICT practices as she was supported by the activities of the learning community. The teacher studied was an ICT mentor in the school and had taught for 6 years. Her motivation for participating in this CSILC was to lead by example for her colleagues in the implementation of innovative ICT-based science inquiry lessons enabled by 1:1 device program the school had embarked on. As part of the study, the ETD officers conducted verbal interviews with the teacher to find out insights into her perceptions and experience over the course of her journey. The team reported that the teacher showed changes in her level of knowledge, self-efficacy, and beliefs.

For example, her initial idea about google site as a mere repository for students to access resources changed to one in which she started to see it as a platform with embedded collaborative elements to facilitate student-centered learning. She also saw herself a member in a larger community, sharing at local cluster sharing and other learning communities, and collaborating with other teachers in designing ICT-based lessons, rather than an individual who designed and carried out lessons. It was also reported that she now believed that students could take more ownership in their own learning through student-centered learning.

This case example illustrates some affordances that made the transformation of a teacher possible – the support from the learning community in sharing and suggesting ideas, the workshops that introduced innovative instructional framework, the partnership with ETD officers who gave suggestions to her on the use of Google Sites and helped to promote buy-in from school management, the observations of implementation by ETD officers and suggestions from them on what improvements to make, and the reflection facilitated by the ETD officers. Overall, the study found three support structures and processes in learning communities that supported the development of the teacher: creating space to address teacher needs and problems of practice, motivating teachers and increasing their commitment to shared professional growth, and fostering organic diffusion of practice through leadership.

Conclusion

The three case examples highlight the benefits of teacher-led research and the affordances that facilitate this teacher-led initiative. The three examples demonstrate the generation of new knowledge and skills for science teaching, which aligns with the TLLM initiative of the Ministry of Education. Facilitating teacher-led research are factors such as "white space" set aside for teachers to come together to explore new pedagogies, communities of science teachers set up among clusters of schools, and expertise from the Ministry of Education who advises teachers in their inquiry as well as ensures alignment with the direction of the ministry's goals. Monetary and leadership supports allow specialized tools for teaching and learning to be made available.

Teacher-as-researcher portrays teaching as an inquiry. In many ways, the case examples in this chapter illustrate that it is a form of practice-based learning involving critical reflection and inquiry. It places teachers at the driver's wheel, who determine how best to bring their students to achieve the intended learning goals. The autonomy increases the professionalism of teachers who not only make evidence-based decisions but also develop deeper insights into their students learning in the process of inquiry. This way, they are at a better position to make decisions that can cater to the needs of their students. Teachers are also making use of the body of literature to inform their pedagogical design. This helps to bring closer the theory-practice nexus that is often said to be absent in schools.

References

Bereiter C, Scardamalia M, Alexander P, Winne P (2006) Education for the knowledge age: design-centered models of teaching and instruction. In: Mahwah N-J (ed) Handbook of educational psychology. Lawrence Erlbaum Associates Publishers, US, pp 695–713

Driver R, Newton P, Osborne J (2000) Establishing the norms of scientific argumentation in classrooms. Sci Educ 84:287–312

Foo-Lam WK, Soh YP, Widodo F, Chia WJA, Heng KJ, Nah WK, LIU X, Sun W, Toh QK (2014) An approach to holistic education– cultivating 21st century competencies using Team-Based Learning (TBL) in the teaching of higher 2 (H2) biology. In: Lee Y-J, Lim NT-L, Tan KS, Chu HE, Lim PY, Lim YH, Tan I (eds) Proceedings of international science education conference 2014. National Institute of Education, Singapore

Lee HL (2004) Our future of opportunity and promise. Prime Minister Lee Hsien Loong's National Rally 2004 Speech, Sunday August 2004, at the University Cultural Centre, NUS. Retrieved from http://www.nas.gov.sg/archivesonline/speeches/view-html?filename=2004083101.htm. Accessed on 14 Apr 2016

Lo K, Soh CP, Chew HC, Lam STS, Wan LK, Gawade S (2014) To improve the planning skill in Chemistry investigation through knowledge building and virtual laboratory. In: Lee Y-J, Lim NT-L, Tan KS, Chu HE, Lim PY, Lim YH, Tan I (eds) Proceedings of international science education conference 2014. National Institute of Education, Singapore

Ministry of Education (n.d.) Teacher growth model. Retrieved from https://www.moe.gov.sg/media/press/files/2012/05/fact-sheet-teacher-growth-model.pdf

Parmlee D, Michaelson LK, Cook S, Hudes PD (2012) Team-based learning: a practical guide: AMEE Guide No. 65. Retrieved from http://www.informahealthcare.com

Poh ML, Phua JYC, Aw ILP, Lin Q (2014) A case study on the professional growth of a science teacher in a learning community. In: Lee Y-J, Lim NT-L, Tan KS, Chu HE, Lim PY, Lim YH, Tan I (eds) Proceedings of international science education conference 2014. National Institute of Education, Singapore

Shanmugaratnam T (2004) To light a fire: enabling teachers, nurturing students. Speech at MOE workplan seminar 2004 on Wednesday, 29 September 2004 at 9.50 am at the Ngee Ann Polytechnic Convention Centre. Retrieved from https://www.moe.gov.sg/media/speeches/2004/sp20040929.htm. Accessed on 14 Apr 2016

Shanmugaratnam T (2006a) Keynote address by Mr Tharman Shanmugaratnam, Minister for Education and Second Minister for Finance, at the Teachers' Mass Lecture 2006 on Monday, 4 September 2006 at 2.30 pm at the Singapore Expo, Hall 8. Retrieved from https://www.moe.gov.sg/media/speeches/2006/sp20060904.htm. Accessed on 14 Apr 2016

Shanmugaratnam T (2006b) Speech by Mr Tharman Shanmugaratnam, Minister for Education and Second Minister for Finance, at the MOE Workplan Seminar 2006, on Thursday, 28 September 2006 at 10.00AM at the Ngee Ann Polytechnic Convention Centre. Retrieved from https://www.moe.gov.sg/media/speeches/2006/sp20060928.htm. Accessed on 14 Apr 2016

Stenhouse L (1975) An introduction to curriculum research and development. Heinemann, London

Takahashi A, McDougal T (2014) Implementing a new national curriculum: a Japanese public school's two-year Lesson-Study Project. In: McDuffie AR, Karp KS (eds) Annual perspectives in mathematics education (APME) 2014: using research to improve instruction. National Council of Teachers of Mathematics, Reston, pp 13–21

Chapter 12
Coherence in the Teaching of South African Chemistry Lessons

Umesh Ramnarain

Abstract This study was on the coherence of chemistry lessons taught by South African physical sciences teachers at historically disadvantaged township schools. Video transcripts of 30 lessons were analyzed and coded using a framework of conceptual coherence developed by the Biological Sciences Curriculum Study (BSCS) for the Science Teachers Learning from Lesson Analysis (STeLLA) project. It was revealed that learners in such classes have experiences that can be regarded as fragmented, disconnected, and incoherent. From this it can be inferred that these experiences limit their conceptual understanding in chemistry, leading to poor performance in the subject. The chapter provides a detailed analysis of two chemistry lessons for conceptual coherence, and from these lessons explicates some of the trends revealed in the overall findings. The implication of these findings is that teachers need to more explicitly sequence ideas, link ideas to one another, and support learners in connecting these ideas to activities they are engaged in.

Introduction

The complex and abstract nature of chemistry makes the subject conceptually challenging to learners (Childs and Sheehan 2009; Treagust and Chittleborough 2001), and this provides fertile ground for investigations in the teaching and learning of chemistry (De Jong and Taber 2014). Many learners have difficulty understanding the macroscopic, submicroscopic, and symbolic perspectives of chemistry phenomena and in particular in appreciating how and when to make the transitions between the three perspectives (De Jong and Taber 2007). In particular, learners who possess limited prior knowledge often have problems with the coordination and integration of multiple representations (Kozma and Russell 1997). According to De Jong and Taber (2014), even the initial knowledge of learners, based on daily life experiences, is often not very fruitful for interpreting chemical phenomena in terms of multiple

---

U. Ramnarain (✉)
University of Johannesburg, Johannesburg, South Africa
e-mail: uramnarain@uj.ac.za

J. Yeo et al. (eds.), *Science Education Research and Practice in Asia-Pacific and Beyond*, DOI 10.1007/978-981-10-5149-4_12

representations. They tend not to use multiple representations but rather concentrate only on one representation, and often this is the more familiar or concrete one (Scanlon 1998; Tabachnek and Simon 1998). These findings indicate that learners experience a lack of coherence in their engagement with ideas related to the multiple representations of chemistry, and they should be more actively supported in their coherence formation process in order to benefit from multiple representations (Seufert 2003). Only if learners are able to construct coherent relations both within and between different representations can they acquire a deeper understanding of chemistry concepts (Seufert 2003).

Conceptual Coherence in Science Teaching and Learning

Coherence in science can best be described as a set of ideas that are related to each other and represent a coherent structure with unifying concepts such as energy transfer, diversity, and evolution of living organisms that are hierarchically specified from elementary to high school (Bybee 2003; NRC 1996; Rutherford 2000). If teachers do not think about accomplishing their learning goals through the selection of appropriate ideas that build to larger concepts, they will contribute to the fragmented, disconnected, and incoherent learning experiences by students (Schmidt et al. 1997). A coherent curriculum is one that has a sense of unity and connectedness, relevance, and pertinence so the ideas have a larger purpose (Beane 1995). This leads to an integrated understanding whereby learners are able to use the interconnectedness of ideas to solve problems and acquire an understanding of the world they live in (Fortus and Krajcik 2012). Bruner (1960) underlined the importance of helping students make connections among ideas by arguing that "the only possible way in which individual knowledge can keep proportional pace with the surge of available knowledge is through a grasp of the relatedness of knowledge" (1995, p. 333).

Conceptual coherence in science learning is underlined in the National Science Education Standards of the USA where it is stated that "understanding science requires students to integrate a complex structure of many types of knowledge, including the ideas of science, relationships between ideas, and reason for these relationships" (NRC 1996).

In South Africa, the notion of coherence is specified in the National Curriculum Statement for physical sciences where it is stated in teaching science there should be "Conceptual coherence both within each grade and between grades" (Department of Education 2003, p.35). According to Dunst and Levine (2014), conceptual coherence is a symmetrical relation between concepts. A concept coheres with another concept if there are objects to which they both apply.

In this research, a "science content storyline" lens conceptualized by Roth et al. (2011) is invoked in investigating the notion of coherence in the teaching of chemistry in South African classrooms. Roth et al. (2011) describe a "science content storyline" as the flow and sequencing of learning activities such that concepts align and progress in ways that are instructionally meaningful to student learning.

Hanuscin et al. (2016) posit that "Sequencing and connecting scientific concepts in a storyline is important because this conceptual structure can help provide meaning to students" (p. 394). It is important to clarify the grain size of a "storyline" as it could refer to how ideas connect at each grade level or in the context of a lesson. In this discussion, the "storyline" refers to conceptual coherence underpinning a single lesson.

South African Education Context

A legacy of the apartheid policies in South Africa is the enormous diversity of schools and inequity in the quality science education. Black learners mainly attend poorly resourced township and rural schools, while in contrast, urban and suburban schools that are largely attended by white learners generally have better facilities and are located in communities with a higher socioeconomic status (Erasmus and Ferreira 2002). In South Africa, townships are usually on the periphery of towns and cities, and the communities have low socioeconomic status. Historically, black South African children have experienced science learning to be both inaccessible and irrelevant. The inaccessibility was related not only to the fact that many learners were not offered the opportunity to do science as a subject but also black learners who did attempt the subject performed poorly (Ramnarain 2011). According to Naidoo and Lewin (1998), the apartheid education policies resulted in black students being "taught by a large number of unqualified science teachers in schools with few or no laboratories and science equipment" (p. 730). Since the advent of democracy in 1994, the South African education system guided by the government White Paper 1 on Education and Training (Department of National Education 1994) has been transformed. The main thrust for science education in this document is the improvement in the quality of school science for black students so that strides toward equity could be made.

Large-scale research in South Africa reveals that despite these efforts, there is little to suggest that the quality of learning has improved for all population groups. For instance, the 2011 Trends in International Mathematics and Science Studies (TIMSS) ranked South Africa at 44 out of 45 countries (Human Science Research Council 2011). According to the Global Competitiveness Report (2014–2015), South Africa ranks 138 out of 140 countries in mathematics and science education quality.

In view of the poor performance in science, especially in chemistry of learners in disadvantaged township schools (Department of Basic Education 2013), the study focuses on the teaching of chemistry at such schools. The importance of coherence was revealed in a study by Schmidt et al. (2005) who found it was the most dominant predictive factor of student achievement. It is against this background that this study pursued the following research question:

To what extent do physical sciences teachers at township schools construct a "science content storyline" in teaching chemistry?

A Science Content Storyline

Roth et al. (2011) identify two key dimensions in pedagogical content knowledge (PCK) of science teachers: (1) knowledge about creating a coherent science content storyline and (2) knowledge about eliciting and supporting. Pedagogical content knowledge is a type of knowledge that is unique to teachers and is based on the manner in which teachers relate their pedagogical knowledge (what they know about teaching) to their subject matter knowledge (what they know about what they teach) (Cochran et al. 1993). Based on their PCK, teachers translate subject content knowledge into useful forms of representations of ideas in the form of "powerful analogies, illustrations, examples, explanations and demonstrations" to facilitate comprehension by students (Shulman 1986, p.9). Good teaching therefore entails a deep and comprehensive knowledge of content in order to be able to elicit and facilitate the development of student ideas, as well as support learners make connections among these ideas.

This chapter presents research on the extent to which chemistry teachers support learners in achieving integrated and coherent understanding by enacting a science content storyline. In orchestrating a science content storyline, a teacher carefully chooses and sequences ideas that build on one another and are linked to lesson activities to help students construct a coherent "story" that makes the content knowledge understandable. Roth et al. (2011) propose the following pedagogical strategies that can be employed in supporting a coherent science content storyline:

- Focusing on one main learning goal
- Setting the purpose with a focus question
- Selecting activities that are matched to the learning goal
- Selecting content representations that are matched to the learning goal
- Linking ideas and activities
- Linking ideas with other content ideas
- Highlighting key ideas
- Sequencing key ideas and activities logically
- Summarizing and synthesizing key ideas

The pedagogical strategies are discussed in much detail by Roth et al. (2011), but for now a brief description is provided for each. The first step in creating a coherent science content storyline is to identify the learning goal or main idea for the lesson. The goal statement focuses the learners' attention on the content learning goal for the lesson and can be posed as a focus question to elicit learners' initial ideas at the beginning of a lesson or lesson sequence. Student activities in science classroom assume many forms such as observing phenomena, constructing models, drawing diagrams, interpreting graphs, group discussions, and so on. In order for these activities to develop the science content storyline, they need to be closely matched to the main learning goal of the lesson. Content representations can be useful in helping make science ideas concrete for learners. They can include analogies, diagrams, charts, graphs, concept maps, models, and role-plays. Activities that learners carry out should be explicitly linked to the science content storyline so that they are challenged to think about content ideas before, during, and after completing an activity. Science ideas introduced in a lesson should be clearly and explicitly linked to the main science idea, and in addition the links between science ideas across lessons should be made visible to learners. The science content storyline will be easier for students to follow if the key ideas are highlighted at certain points during the lesson. The teacher can do this by writing the key ideas on the board, summarizing at key transition points in the lesson, or guiding students to underline or highlight the key sentences on a worksheet. The order in which content ideas and activities are introduced in a lesson should be carefully planned. Although this can be done using various approaches, it is imperative that the storyline is scientifically accurate, closely matches the main learning goal, and makes sense to the learners. A science content storyline needs to be tied up at the end of the lesson by way of a summary or synthesis activity that makes connections between the content ideas and activities and also highlights how they support the main learning goal. The summary might be constructed by the teacher and learners together during a class discussion or by learners independently in small group discussions or individual writing tasks.

The Science Teachers Learning from Lesson Analysis (STeLLA) project is a video-based analysis-of-practice professional development program that applied these strategies in improving teacher and student learning at the upper elementary level (Roth et al. 2011). In the STeLLA project, teachers explored videocases of science lessons through a series of tasks where they practiced identifying and then analyzing the strategies used in the videocases. However, in this study the strategies constituted a conceptual lens by which coherence in chemistry teaching is studied. This meant that the strategies underlined in this lens were adopted as indicators of teacher action in facilitating conceptual coherence in chemistry teaching.

Method

Participants

The author contacted 30 physical sciences teachers who were teaching at township schools in the northeastern province of Gauteng to recruit them in the study. Finally, ten teachers agreed to participate in the study. Both schools were located in a densely populated township in the province of Gauteng. The schools were poorly resourced, and there was a genuine lack of equipment and chemicals for practical work in science. The learners came from poor socioeconomic backgrounds. School A had an overall pass rate of 65% in the previous Grade 12 national high-stakes exit examination, with only 23% of learners achieving above 50% in the physical sciences examination. The annual school fee was R1000 (US$70), with a 63% collection rate. The average physical sciences class size was 43. Miss Masego (pseudonym), the physical sciences teacher at this school, has a teaching degree with teaching majors in physical sciences and mathematics. She had taught the subject for 14 years. School B had a similar profile as school A, with learners achieving a pass rate of 68% in the previous years' national exit examination and 21% of learners scoring above 50% in the physical sciences examination. The average physical sciences class size was 45 learners. Mr. Mbele (pseudonym) had taught physical sciences over the past 13 years in the school. He majored in physical sciences and life sciences and had a teaching degree.

Data Collection

Data were collected by means of classroom observations. Two chemistry lessons were observed for each teacher within a period of 3 weeks. The lessons were conveniently selected based on the availability of the researcher. The lessons were video recorded and later transcribed. Transcripts of lessons were analyzed using the conceptual lens of science content storyline. The strategies underlined in this framework were adopted as indicators of teacher action facilitating conceptual coherence in the lesson. The lessons were therefore coded for the visible use of teacher action. The following coding scheme was used for each action: 0 = not achieved, 1 = partially achieved, and 2 = completely achieved. In this way the frequency of the action, as well as the time spent on each action, was established. An action is coded completely achieved if it is explicit in enactment. For example, in the action "setting the purpose with a focus question," a question such as "What are the physical properties of acids?" is considered completely achieved due to its explicitness, whereas for the action "Identify one main learning goal," a teacher who addresses this by stating "Today we will be looking at alkanes" does not explicitly state the main learning goal, and so this action is coded "partially achieved."

The coding was done independently by the author and another researcher in science education. Prior to the coding, a meeting was held between the two researchers whereby the coding scheme was discussed, and excerpts from other lessons were used to demonstrate the coding. The inter-rater reliability was 74%. Differences in the rating were later resolved in a discussion, and consensus was reached. Thereafter, the lesson was looked at holistically, and an overall judgment was made on coherence. This was done calculating the mean score for teacher actions. Here all the scores for each teacher action were added and then divided by the number of teacher actions.

Result

Table 12.1 presents the results of the 20 lessons that were observed.

The above results show that for the lessons observed, the teaching actions associated with coherence were poorly manifested. The mean scores for all the actions

Table 12.1 Means and standard deviations of observed teaching action

Observed teaching action	Mean score for achieved teaching action	Standard deviation
Identify one main learning goal	1.13	0.39
Set the purpose by using goal statements and focus questions	1.05	0.25
Select activities that are matched to the learning goal	0.87	0.38
Provide opportunities for students to use content representations matched to the learning goal	0.75	0.47
Link science content ideas and activities	0.78	0.36
Link content ideas to other content ideas	0.89	0.25
Highlight key ideas	0.87	0.31
Sequence key ideas and activities appropriately	0.94	0.45
Summarize and synthesize key ideas	0.89	0.42

apart from 2 ranged between “0” (not achieved) and “1” (partially achieved). The low standard deviations showed that there was much consistency in the extent to which these actions were evidenced in the lessons. The only two actions that questions yielded scores marginally above “1” were on “Identify one main learning goal” and “Set the purpose by using goal statements,” indicating that these actions were only partially achieved. These two teacher actions when enacted were in large part evidenced at the beginning phase of the lesson and did suggest that these teachers were pursuing an outcome in the lesson. All other teacher actions for conceptual coherence were largely absent.

For the purposes of this paper, two lessons taught by each of two teachers were analyzed in greater detail, with the goal to substantiate some of the findings revealed above. The lessons provided evidence of some of the trends revealed. Below excerpts on the teaching actions for the science content storyline where evident were described and then interpreted in terms of coherence.

Miss Masego’s Grade 11 Lesson on Acids and Bases

The lesson was extended over two periods for 35 min each.

Identify One Main Learning Goal

At the beginning of the lesson, Miss Masego announced “we are going to talk about the acids and bases.” She did not clearly articulate to the learners the main idea for the lesson but merely stated the topic. Furthermore, she did not specify to learners what they were expected to learn in terms of acquiring knowledge and/or developing a skill. This teaching action was therefore coded "partially achieved."

Set the Purpose by Using Goal Statements and Focus Questions

During the course of the lesson, the teacher asked learners to list examples of household acids and bases. In introducing the Lowry-Bronsted theory of acids and bases, the teacher asked learners to complete the statement "When an acid donates, a base must…." Before explaining the dilution of an acid, the teacher asked "You know how to dilute an acid?" Although these focus questions did to a certain extent relate to the main goal statement referred to above, they were not meaningful for learners as they do not connect with their existing ideas on acids and bases. This teaching action was coded as "partially achieved."

Select Activities That Were Matched to the Learning Goal

The teachers did not involve learners in any activity in support of the learning goals. The lesson was heavily dominated by teacher explanations from notes, and this was punctuated with the teachers enquiring from learners about their understanding by asking "Is it clear so far?" and "Do you all follow?" At times, she posed a question that related to their existing knowledge. When there was a lack of response or incorrect response, she followed up with prompting questions. For example, when a learner suggested "Sulfuric acid" as an example of a domestic acid, Miss Masego prompted them toward the correct answer by saying "Class I am talking about the things that taste sour and we are using those things in our homes." Such prompting questions were infrequent, and they were not regarded as learner activities. This teaching action was coded as "not achieved."

Provide Opportunities for Students to Use Content Representations Matched to the Learning Goal

Much of the lesson was taken up by the teacher to unpack the content using explanations. To a large extent, she relied on notes that resembled material from a textbook that was approved by the education ministry. The discourse was predominantly scientific, and there were only a few occasions where the teacher connected the scientific knowledge to the everyday experiences of learners. An example of this was when after explaining the dilution method for an acid, she referred learners to the dilution of "Oros juice." There was no evidence of other content representations such as analogies, diagrams, charts, graphs, concept maps, models, and role-plays that could help make science ideas concrete for learners. There was a disagreement between the coders on whether the "Oros juice" example was significant enough for this teaching action to be regarded as "not achieved" or "partially achieved." Eventually due to the scant attention given to this action in the overall lesson, it was agreed that it would be coded as "not achieved."

Link Science Content Ideas and Activities

There were no instances of the teacher facilitating the connection of content ideas and activities. As mentioned previously, the emphasis was on the exposition of content, with little or no engagement of learners on this. This teaching action was coded as "not achieved."

Link Content Ideas to Other Content Ideas

The key content ideas included domestic acids and bases, the ionization of acids in water, strengths of acids, dilution of acids, dissociation of bases, strengths of bases, the dilution of acids, the Lowry-Bronsted theory of acids and bases, and conjugate acid-base pairs. Despite the obvious conceptual link between these ideas, they were largely presented to learners in fragments and in isolation from each other. There was no attempt by the teacher to help learners make connections between ideas. There was also no evidence of any conceptual link between the previous and subsequent lessons. Due to this action not being achieved, the content ideas that were presented came across as being "bits and pieces" and at times incoherent. This teaching action was considered to be "not achieved."

Highlight Key Ideas

There was little evidence of the teacher highlighting key ideas. The only occasion where this action was displayed was when after explaining conjugate acid-base reactions, Miss Masego stressed that the "conjugate acid is always formed when a base accepts a hydrogen ion." This teaching action was therefore rated as "partially achieved."

Sequence Key Ideas and Activities Appropriately

The key ideas were presented in the following order: domestic acids and bases, the ionization of acids in water, strengths of acids, dilution of acids, dissociation of bases, strengths of bases, the dilution of acids, the Lowry-Bronsted theory of acids and bases, and conjugate acid-base pairs. At a conceptual level, the order of these ideas did support coherence due to the sequencing of ideas from concrete to the more sophisticated. However, the sequencing of these ideas was not integrated with activities. It was therefore decided to classify this action as “partially achieved.”

Summarize and Synthesize Key Ideas

The lesson ended quite abruptly with the teacher asking “Do you have any questions? Is there something that you don’t understand here?” There was no evidence of the teacher summarizing and synthesizing key ideas on the topic and thereby “tying up” the science content storyline. This teaching action was considered “not achieved.”

Overall Assessment of Miss Masego’s Lesson

The scoring for Miss Masego’s lesson is summarized in Table 12.2. Overall, the lesson revealed sparse evidence of teaching actions that supported a science content storyline.

This is underlined quantitatively by the total score 4 for the teaching actions out of a possible score of 18. This equates to 22% for a coherent science content storyline. The above analysis shows that the content ideas presented by the teacher were fragmentary and lacked cohesiveness, resulting in a conceptual disconnect between

Table 12.2 Scoring of Miss Masego’s lesson

Observed teaching action	Score
Identify one main learning goal	1
Set the purpose by using goal statements and focus questions	1
Select activities that are matched to the learning goal	0
Provide opportunities for students to use content representations matched to the learning goal	0
Link science content ideas and activities	0
Link content ideas to other content ideas	0
Highlight key ideas	1
Sequence key ideas and activities appropriately	1
Summarize and synthesize key ideas	0

the ideas. As many as nine key ideas on acids and bases were presented to learners in a double period lesson. Although there was a semblance of sequencing to the ideas, they were presented as disconnected ideas.

Mr. Mbele's Grade 11 Lesson on Redox Reactions

This lesson was extended over two periods for a total duration of 50 min.

Identify One Main Learning Goal

After a brief review of oxidation number that had been taught in a previous lesson, Mr. Mbele informed the class "Now we are going to learn about the redox reaction." He did not communicate any further information on this learning goal and then proceeded to describe a redox reaction in terms of oxidation and reduction processes. The content that underlied redox reactions was quite broad and in-depth, but the statement of the learning goal did not definitively demarcate for learners the content they would learn. We therefore decided to regard this teaching action as "partially achieved."

Set the Purpose by Using Goal Statements and Focus Questions

During the course of the lesson, the teacher announced that they were going to do an experiment to illustrate oxidation and reduction reactions. There was no focus question in relation to this goal statement to guide the investigation. During the reaction between copper sulfate and zinc, a thermometer was used to track temperature changes. However, the teacher did not indicate to learners the purpose of monitoring the temperature changes during this reaction. It was only later that the purpose of this taking the temperature became apparent when the teacher remarked "If the temperature is constant, that means the reaction equilibrium has been reached." Further in the lesson, the teacher asked learners to classify the reaction as either exothermic or endothermic based on the temperature change that occurred. Due to the lack of a clear goal statement and related focus question, this teaching action was coded as "partially achieved."

Select Activities That Are Matched to the Learning Goal

The learners were engaged in a group practical activity. The teacher announced that the purpose of this activity was to "do an experiment on the direct transfer of electrons in oxidations and reduction reactions." This was referred to as experiment A in the worksheet that was handed out by the teacher. The teacher went on to give instructions on how to conduct the practical that involved the reaction between a solution of copper sulfate and zinc powder. However, it later became evident that the real purpose of the experiment was for the learners to establish whether the reaction was exothermic or endothermic.

The second activity that was referred to as experiment B in the worksheet was a teacher demonstration on the reactions between a copper sulfate solution and a zinc plate. At the start of this activity, the teacher stated "now we are going to compare in this too the type of reaction. Whether which one is fast, which one is slow. We have done A, now we go to B." The impression created here is that the focus of the activity is on the comparison of the rates of reaction. During the course of the activity, the teacher highlighted the color change of the solution and the increase in the mass of the zinc plate. During this reaction, the teacher prepared hydrogen sulfide gas by reacting iron sulfide and hydrochloric acid and then bubbled this gas through the copper sulfate solution. There was a formation of a white precipitate, but he did not explain the significance of this precipitate.

Although both activities were relevant to the learning of redox reactions as the overarching goal, he did not clearly communicate to learners the purpose of the activities. This teaching action was therefore regarded as being "partially achieved."

Provide Opportunities for Students to Use Content Representations Matched to the Learning Goal

The learners did experience firsthand a redox reaction between copper sulfate and zinc. The teacher did draw their attention to the copper sulfate solution that was gradually losing its blue color and the reddish-brown deposit on the zinc plate. After the experiment, the teacher explained these observations by referring to electron transfer between zinc and copper. He communicated this as follows: "Zinc is going to lose two electrons. If it loses two electrons, those electrons are going to be gained by copper. The copper ions are going to gain two electrons to give us copper." The teacher then referred learners to the table of standard electrode potentials and proceeded to explain that "the further a substance is down the table, the stronger oxidizing ability it will have." Although both the practical activity and the table of standard electrode potential are appropriate forms of representations for learning about redox reactions, the match between these representations and the main learning goal was blurred because the teacher did not effectively use the representation to support the learners in grasping the concepts of oxidations and reduction. This teaching action was coded as "partially achieved."

Link Science Content Ideas and Activities

Despite the attention that was given to the macroscopic changes taking place in the reactions between zinc and copper sulfate, the teacher did not adequately connect these changes to the chemistry taking place at the submicroscopic level. He was not explicit about the processes of oxidation and reduction taking place in terms of the one substance losing electrons and the other gaining electrons.

In experiment B where hydrogen sulfide gas was bubbled through the solution, it was not made apparent to learners that the formation of the zinc sulfide white precipitate was evidence of the formation of zinc ions in solution. Here again the link between the content idea and the activity was not established.

A further example of this disconnect was the teacher discussion of the table of standard electrode potential. The teacher spent much time telling learners about trends that can be inferred from the table such as "the substance at the bottom will have the strongest oxidizing ability" and "the upper part of the arrow in the half-reactions shows the strongest reducing." However, there was a lack of a clear and decisive explanation of the meaning of the electrode potential values and what can be deduced from them. The teacher explanations were conveyed as rules that should be followed.

This teaching action was coded "not achieved."

Link Content Ideas to Other Content Ideas

The key content ideas included redox reaction, oxidation, reduction, direct transfer of electrons, exothermic, endothermic, and standard electrode potentials. Despite the obvious conceptual link between the ideas and opportunities whereby this could be established, to a large degree, the ideas were taught in isolation. For example, despite acid-base reactions being taught prior to redox reactions, and some similarity between these two types of reactions where the one involves a transfer of protons and the other a transfer of electrons, the teachers did not explicitly support learners in making this link. This teaching action was considered "not achieved."

Highlight Key Ideas

There were a few instances where the teacher did highlight a key idea. For example, when referring to oxidation, he stressed "In oxidation remember we said that's when we have LEO which is loss of electrons." On another occasion he highlighted "If energy is released then that type of reaction that is taking place is exothermic." Due to some ideas being highlighted and others not, it was decided to regard this teaching action as "partially achieved."

Sequence Key Ideas and Activities Appropriately

The key ideas and activities were presented in this order: redox reactions, electrons transfer, oxidation, reduction, experiment on redox reaction between zinc power and copper sulfate solution, experiment on redox reaction between zinc plate and copper sulfate solution, exothermic and endothermic reaction, and standard electrode potential table. There was proper sequencing of ideas whereby the teacher introduced redox reactions and then discussed oxidation and reduction, leading to the practical activity. However, in the practical activity, the teacher also addressed exothermic and endothermic reactions, and this was considered to be out of place with regard to the main learning goal. As a result, this teaching action was rated "partially achieved."

Summarize and Synthesize Key Ideas

There was no evidence of this teaching action. The teacher concluded the lesson by handing learners a worksheet and asking them to complete this for the next lesson. This teaching action was "not achieved."

Overall Assessment of Mr. Mbele's Lesson

The scoring for Mr. Mbele's lesson is summarized in Table 12.3. Again, as was the case with the previous lesson discussed, Mr. Mbele's lesson did not depict a clear and coherent science content storyline.

A total score of 6 was achieved for the teaching actions out of 18, and this equated to 33.3% for overall coherence. Although learners were engaged in practical activities, the link between these activities and the key content ideas needed to be made more visible.

Table 12.3 Scoring of Mr. Mbele's lesson

Observed teaching action	Score
Identify one main learning goal	1
Set the purpose by using goal statements and focus questions	1
Select activities that are matched to the learning goal	1
Provide opportunities for students to use content representations matched to the learning goal	1
Link science content ideas and activities	0
Link content ideas to other content ideas	0
Highlight key ideas	1
Sequence key ideas and activities appropriately	1
Summarize and synthesize key ideas	0

Discussion

The findings of this study on the practice of physical sciences teachers at a township in South Africa revealed the lack of a coherent science content storyline in chemistry lessons. Learners in these classes had fragmented, disconnected, and incoherent learning experiences of key ideas that compromised an integrated understanding of chemistry concepts from macroscopic, submicroscopic, and symbolic perspectives. It can be inferred that such experiences may be one of the reasons for the poor performance of learners in the subject. It has already been pointed out that South Africa compares poorly with other countries in international assessments such as TIMSS, and the findings reported in this chapter suggest that the lack of conceptual coherence in chemistry learning could be a contributing factor to poor achievement.

In contrast, Roth et al. (2011) maintained that in higher-achieving countries such as Finland and Singapore, "teachers more commonly used activities to develop science ideas, and organised lessons in a way that resembled a storyline" (p.120). The teachers in high-achieving countries made explicit connections between the opening focus question, the science ideas, the activities, the follow-up discussions of activities, and the summary of the lesson. In low-achieving countries, there was little evidence of teachers supporting students in linking observations and experiences to conceptual science ideas. Indeed, the findings of research reported in this chapter on under-achieving South African schools are coherent to the findings reported in studies done in the USA (e.g., Roth et al. 2006). The TIMSS Video Study found that eighth-grade US science lessons focused on doing activities with less attention to the science content and even less attention to the links between activities and science ideas. This is a concern because building conceptual understanding of critical science ideas requires learners to interconnect knowledge in a manner that is coherent. A science content storyline depicts such coherence and is hence supportive of science learning.

The teacher is key to enacting coherence in science learning. The findings showed that teachers displayed a deficit of actions in orchestrating learning situations that supported coherent learning experiences. As has already been pointed out, a legacy of the apartheid policy in South Africa is that black students at township schools tend to be taught by teachers who are less qualified than their white counterparts at suburban schools. This has implications for teacher professional development efforts at the preservice and in-service levels. There needs to be more deliberate and explicit attempts toward attuning teachers toward actions that construct a science content storyline. Professional development focused on the construction and analysis of conceptual storylines may help teachers plan and implement lessons with conceptual coherence (Hanuscin et al. 2016). One such approach could be the analysis of practice (Grossman et al. 2009) using videocases as reported in the Science Teachers Learning from Lesson Analysis (STeLLA) project (Roth et al. 2011). The STeLLA project researched a professional development program whereby teachers explored videocases through a series of tasks that drew teachers' attention to how the science ideas in a science lesson or unit are sequenced and linked to one another and to lesson activities (Roth et al. 2011). The pedagogical strategies for a "science content storyline" that were employed as indicators of coherence in this study can be used as a guideline by teachers in creating a coherent science content storyline.

In addition, a study by Hanuscin et al. (1996) demonstrated how professional developers can use tools such as the Conceptual Storyline Probe that engages teachers in comparing and contrasting two lessons on the same topic that differ with regard to conceptual coherence. Such explicitness to teacher actions in enacting conceptual coherence "forces" teachers to reflect more closely on their own teaching practice.

It was evident in lessons, for example, the lesson by Miss Masego, that teachers exhibited a reliance on materials from textbooks in directing their lessons. Research conducted in South Africa (Ramnarain and Padayachee 2015; Malcolm and Alant 2004) has revealed that there is an overreliance on textbooks by science teachers. This calls for a closer introspection of curriculum materials for the manner to which these materials represent conceptual coherence.

In view of the diversity of schools in this country, further research could investigate how contextual factors such as teacher qualification, class size, resource, and school culture intersect with conceptual coherence in science teaching. This study focused on the teaching of chemistry at historically disadvantaged township schools in South Africa due to the poor performance of students in this subject. It would be of interest to investigate and compare how teachers at suburban schools where student achievement in science is higher enact conceptual coherence in their teaching.

References

Beane J (1995) Conclusions: toward a coherent curriculum. In: Beane J (ed) Toward a coherent curriculum. Alexandria, Association for Supervision and Curriculum Development

Bruner J (1960) The process of education. Harvard University Press, Cambridge, MA

Bybee RW (2003) Science curriculum reform in the United States. National Academy of Sciences, Washington, DC

Childs PE, Sheehan M (2009) What's difficult about chemistry? An Irish perspective. Chem Educ Res Pract 10:204–218

Cochran KF, DeRuiter JA, King RA (1993) Pedagogical content knowing: an integrative model for teacher preparation. J Teach Educ 44:263–272

De Jong O, Taber K (2007) Teaching and learning the many faces of chemistry. In: Abell SK, Lederman NG (eds) Handbook of Research on Science Education. Lawrence Erlbaum Publishers, Mahwah, pp 631–652

de Jong O, Taber KS (2014) The many faces of high school chemistry. In: Lederman N, Abell SK (eds) Handbook of research in science education volume 5. Routledge, New York, pp 457–480

Department of Basic Education (2013) Senior certificate examination: technical report. Government Printer, Pretoria

Department of Education (2003) National curriculum statement grades 10–12: physical sciences. Government Printer, Pretoria

Department of National Education (1994) White paper 1 on education and training. Government Printer, Pretoria

Dunst B, Levine A (2014) Analogies great and small, and the quest for coherence. In: Matthews M (ed) History and philosophy of science and science teaching handbook. Springer, Dordrecht, pp 1345–1361

Erasmus P, Ferreira GV (2002) Black grade 9 learners in historically white suburban schools and their experience of integration. South Afr J Educ 22(1):28–35

Fortus D, Krajcik J (2012) Curriculum coherence and learning progressions. In: Fraser BJ, Tobin KG, McRobbie CJ (eds) The International Handbook of Research in Science Education, 2nd edn. Springer, Dordrecht

Grossman P, Compton C, Igra D, Ronfeldt M, Shahan E, Williamson P (2009) Teaching practice: a crossprofessional perspective. Teach Coll Rec 111(9)

Hanuscin D, Lipsitz K, Cisterna-Alburquerque D, Arnone KA, Van Garderen D Kozma RB, Russell J (1996) The use of linked multiple representations to understand and solve problems in chemistry. Report Oakland University

Hanuscin D, Lipsitz K, Cisterna-Alburquerque D, Arnone AA, van Garderen D, de Araujo Z, Lee JE (2016) Developing coherent conceptual storylines: two elementary challenges. J Sci Teach Educ 27:393. doi:10.1007/s10972-016-9467-2

Human Science Research Council (HSRC) (2011) Highlights from TIMSS 2011 the South African perspective. Human Science Research Council (HSRC), Pretoria

Kozma R, Russell J (1997) Multimedia and understanding: expert and novice responses to different representations of chemical phenomena. J Res Sci Teach 43:949–968

Malcolm C, Alant B (2004) Finding direction when the ground is moving: science education research in South Africa. Stud Sci Educ 40:49–104

Naidoo P, Lewin J (1998) Policy and planning of physical science education in South Africa: myths and realities. J Res Sci Teach 35(7):729–744

National Research Council (1996) The national science education standards. National Academy of Sciences. National Academy Press, Washington, DC

Ramnarain U (2011) Equity in science education in South Africa: a pious platitude or an achievable goal. Int J Sci Educ 33(10):1353–1371

Ramnarain U, Padayachee K (2015) A comparative analysis of South African life sciences and biology textbooks for the inclusion of the nature of science. South Afr J Educ 35(1):1–8

Roth KJ, Druker SD, Garnier HE, Lemmens M, Chen C, Kawanaka T, Rasmussen D, Trubacova S, Warvi D, Okamoto Y, Gonzales P, Stigler J, Gallimore R (2006) Teaching science in five countries: results from the TIMSS 1999 video study (NCES 2006–011). National Center for Education Statistics, Washington, DC

Roth KJ, Garnier HE, Chen C, Lemmens M, Schwille K, Wickler NIZ (2011) Videobased lesson analysis: effective science PD for teacher and student learning. J Res Sci Teach 48(2):117–148

Rutherford J (2000) Coherence in high school science. In: Making sense of integrated science: a guide for high schools. BSCS, Colorado Springs, pp 21–29

Scanlon E (1998) How beginning students use graphs of motion. In: van Someren M, Reimann P, Boshuizen HPA, de Jong T (eds) Learning with multiple representations. Elsevier, Oxford, pp 67–86

Schmidt WH, McKnight CC, S. A. Raizen. S.A. (1997) A splintered vision: an investigation of U.S. Science and Mathematics Education. Kluwer Academic Publishers, Boston

Schmidt W, Wang H, McKnight C (2005) Curricular coherence: an examination of US mathematics and science contents standards from an international perspective. Curr Stud 37(5):525–559

Seufert T (2003) Supporting coherence formation in learning from ultiple representations. Learn Instr 13(2):227

Shulman LS (1986) Those who understand: knowledge growth in teaching. Educ Res 15:4–14

Tabachnek HJM, Simon HA (1998) One person, multiple representations: an analysis of a simple, realistic multiple representation learning task. In: van Someren M, Reimann P, Boshuizen HPA, de Jong T (eds) Learning with multiple representations. Elsevier, Oxford, pp 197–236

Treagust DF, Chittleborough G (2001) Chemistry: a matter of understanding representations. In: Brophy J (ed) Subject-specific instructional methods and activities. Elsevier Science Ltd, Amsterdam

Chapter 13
A Collaborative Classroom-Based Teacher Professional Learning Model

Dace Namsone and Līga Čakāne

Abstract This article reviews the Latvian experience of exploring a teacher continuous professional learning model, with an emphasis on teacher collaboration for professional learning. The developed model focuses on lessons taught in real-life classrooms and their subsequent analysis. The model consists of a set of regularly scheduled workshops in a period of a school year. It is based on the idea of a multiple activity cycle of "observe–reflect–write–discuss" conducted several times during every workshop. Every participant has an opportunity to experience two roles: that of *a leader*, teach a demonstration lesson to his/her colleagues, and that of *a learner*, observe, analyse and reflect on a colleague's lesson. The sessions were led by experienced education practitioner coaches.

The model was implemented during the period from November 2011 to April 2015. The teams consisted of experienced, committed teachers from the "Science and Mathematics" project as well as primary school teachers from the national innovative experience schools collaboration network. Surveys from teachers and feedback from expert coaches and teachers demonstrate that the model enhanced the development of teaching, reflection and collaboration skills. The research concludes that the initial science and mathematics teacher learning model can successfully be transferred for professional development in other subjects.

Introduction

Implementation of education reforms in Latvia, as in many countries, triggers a change of teaching paradigms. Reforms in Latvia have focused on promoting an inquiry-based approach to teaching science and mathematics and call for an extensive use of information and communication technology in the classroom. Preparing students for the twenty-first century is at the focus of these changes. When reforms were introduced in 2008, teachers were expected to employ new teaching and learning strategies. Regrettably, during their university education,

---

D. Namsone (✉) • L. Čakāne
University of Latvia, Riga, Latvia
e-mail: dace.namsone@lu.lv; liga.cakane@lu.lv

J. Yeo et al. (eds.), *Science Education Research and Practice in Asia-Pacific and Beyond*, DOI 10.1007/978-981-10-5149-4_13

most teachers working in Latvia today never had a formal introduction to teaching strategies such as how to facilitate group work, conduct formative assessment or set learning goals for their students (Volkinsteine et al. 2014). Teachers find they have to try out new strategies on their own and address the question – how is this working in my classroom? This is a challenge for both teachers and teacher educators because the traditional teacher professional training model, comprised of in-service training courses, cannot be utilized in this setting. The acquisition of passive knowledge about how to successfully implement inquiry-based learning is not sufficient for actual changes to happen (Fullan 2011a). Changes occur when teachers are involved in an ongoing process of active participation in professional development.

A new teacher professional learning model has to be developed to help teachers acquire understanding through implementing changes in their own teaching practice, observing colleagues and reflecting on the effectiveness of his/her teaching. The continuous collaborative teacher professional learning model (CCTPLM) described in this article was developed through experiences first with science and mathematics teachers and then implemented with other groups of teachers. Professional development in this project is based on the principle that teachers must experience first-hand content-specific learning in the same way that he/she is expected to teach his/her students. Therefore, professional development must focus on experiences different from those often found in current practices in teacher continuing education. It is one of the cornerstones of a paradigm shift in the classroom.

Background

What Was Accomplished in the Project "Science and Mathematics"?

The EU-funded project "Science and Mathematics" developed and piloted a new seventh to ninth (ages 13–15) grade curriculum and teaching materials during 2009–2011 school years. While working on the development of teacher professional education, a successful collaboration model was developed in those schools whose team included science and mathematics teachers as well as a representative from the school administration. The results agree with Fullan's (2011b) work: "Well-developed teamwork improves the quality of practices as teachers work and learn from each other". Collaboration within this model is comprised of sharing materials and teaching strategies. Teachers work together in teaching, planning and discussing teaching strategies.

What Was Learned in the PROFILES Project?

The Professional Reflection-Oriented Focus on Inquiry-based Learning and Education through Science (PROFILES) project (funded by the European Seventh Framework Programme "Science in Society") model aims were to promote inquiry-based science education (IBSE) by enhancing science teachers' self-efficacy and sense of ownership of the teaching materials and methodology via a multistage. This model recognizes the importance of motivation and discovery as a social endeavour in the real world. The teacher is viewed simultaneously *as a learner* and *as a teacher*, *as a reflective practitioner* and *as a leader* according to the PROFILES project philosophy. It provides teachers with support according to their needs and guides them to implement IBSE in their classrooms (Hofstein and Mamlok-Naaman 2014). The meaning of leadership in this context is highly aligned with the definition by Fullan (1991): "The ability of a person to bring about changes among teachers and teaching". As part of the PROFILES project, action research groups formed by teachers using the "observe–reflect–write–discuss" cycle (Kemmis and McTaggart 2000) were piloted for the first time in Latvia (Volkinsteine et al. 2014).

What Does Previous Research Show About Teacher Success in Implementation of Innovative Teaching Practice? How Does It Relate to Teacher Learning?

Our experiences in lesson observation (Volkinsteine et al. 2014; France et al. 2015) are similar to those found in the research literature. We believe one strong influence on educational traditions, and the content of Latvian teacher education programmes stems back to the Soviet era of the country's history. An analysis of teaching practices found that in former Soviet countries, the focus is on whole-class instruction versus individual instruction and uniformity of the class versus individual needs of students. In addition, they found a theoretical approach to inquiry versus empirical approach and that content was considered far more important than practice (Pavlova and Pitt 2003; Kozliak 2000). Other research suggest that teachers in former Soviet countries may well be more comfortable with teacher-directed and teacher-controlled lessons and value their knowledge of the subject higher than their teaching skills (Olson 2003; Sanger et al. 2001).

Classrooms where the teacher is the transmitter of information with a focus on learning facts are rooted in teacher education traditions. Teachers acquire formal knowledge through the university and in-service training. Traditionally a science teacher in Latvia is educated to teach a single subject (chemistry, physics or biology) and completes a programme in which up to 90% of the focus is on science content. Moreover, in-service professional development is also a transmission of new information.

Schools in Latvia generally employ one teacher for each of the science subjects: physics, chemistry and biology. The exchange of experiences among teachers in a school or between schools is limited or focused mainly on the dissemination of new information. Van Driel describes a teacher's practical knowledge as the synthesis of experiential knowledge, formal knowledge and personal beliefs (Van Driel et al. 2001). The practical knowledge of many teachers is limited to their personal experiences and the manner in which they were taught in school. These in turn often emphasize the factual and descriptive nature of science, and these views are transferred to the student (Roehrig and Luft 2004).

While the new curriculum requires changes in the approaches and methodologies, many teachers prefer to use a teacher-centred model. Professional development must address this present dilemma in school practice. The introduction of scientific inquiry in the curriculum requires that teachers change from a question/answer model to discussion, from questions that have a single correct solution to multiple correct answers and from transmitting knowledge to discovering it. This requires a change in classroom interactions as well. Teachers must be comfortable with students working in groups instead of individually. In order to master this approach, teachers need new experience beyond mere description of new teaching methods and must change their own understanding of teaching concepts. Teachers must experience inquiry-based learning themselves and be convinced that students will learn better if they are part of the process and not more observers. Teachers' beliefs can only be changed when they become deeply involved in their own practice, that is, by developing reflection skills and collaboration with colleagues.

Our previous observations and research in implementation of new approaches and methods in the classroom point to the crucial need for new methods of teacher education and even more – the development of deeper reflection skills (Namsone and Cakane 2012). However, new teaching approaches and methods in the classroom bring a certain level of risk of not being effective (Fullan and Langworthy 2014). Table 13.1 describes some of these risks. The skilled practitioner must become an activator of learning (Hattie 2012) by continuously assessing the students' learning process.

During the piloting of the project "Science and Mathematics", teachers showed successful teaching performance in the classroom. However, coaches from the National Centre for Education (NCE) involved in the piloting witnessed frequent cases that needed further attention. Teachers taught the elements of scientific inquiry but in the traditional information transfer model. The teachers did not recognize that the transmission of information was ongoing (Volkinsteine et al. 2014). For example, coaches observed chemistry lessons in which teachers were sure that they were teaching scientific inquiry showed that in about 40% of cases, the teachers performed guided inquiry. In the remaining set of lessons, they introduced separate elements, for example, prescribed data collection. Consequently, the students had no possibility to engage in their own intellectual inquiry. There were situations where the students could have discussed the problem, devised experiments them-

Table 13.1 Effective vs. ineffective new pedagogies

Effective new pedagogies (high levels of pedagogical capacity needed)	Ineffective new pedagogies
Establish students and teachers as co-learners	Too much student autonomy
Long-term deep learning tasks; cross-curricular; complex, interdependent tasks	Short-term tasks for one unit or lesson; not multidisciplinary
Deep learning tasks have clear learning goals and clearly defined measures of success	No clear learning goals or ways of measuring success
Give students control and choice suited to their level, gradually building students' capacity to manage the learning process	Give too much control and choice to students before they have skills to structure their own learning effectively
Continuous, effective feedback; formative assessment towards the learning goals	Ineffective feedback or only summative assessment at end of task
Identify and use digital tools and resources to support deep learning tasks and to help students master the learning process. Analyse progress data to inform changes in teaching and learning strategies	Use digital tools and resources only to deliver content and track progress but not to inform changes in teaching and learning strategies

Adopted from Fullan and Langworthy (2014)

selves and carried out data collection and analysis. However, the class was dominated by the teacher. Students became passive observers of the lesson. When the lessons were analysed and reflected on, discussion with the teachers revealed that the teachers thought their performance qualified as scientific inquiry. Although the assigned task contained a short scenario and the problem, scientific inquiry during the lesson was implemented as a frontal, teacher-controlled process of delivering information which involved questioning and practical seatwork. This corresponds to what is found in the literature – in most countries where IBSE is a new approach to teaching education, experts point to the teachers' difficulty in truly implementing scientific inquiry (Anderson and Michener 1994; Bybee and Fuchs 2006). There is a discrepancy between the actual performance of the teachers in the classroom and their understanding of what they were doing (Volkinsteine et al. 2014).

Lessons observed in more recent research revealed the presence of a similar problem in mathematics (France et al. 2015) as well as other branches of science. This demonstrates the urgency of improving teacher reflection skills for working with the new curriculum. Previous research (Namsone et al. 2012) identified learning needs defined by teachers themselves. In surveys on what they felt they needed in professional development, teachers frequently listed how to develop higher-order cognitive skills in students as well as a number of teaching-related issues. However, teachers did not mention the development of reflection and teacher collaboration skills as an urgent need. This points to another challenge in implementation of professional learning as teachers need to be trained in skills for which they, themselves, fail to see the importance.

Literature Concerning Teacher Impact, Learning and Collaboration

The literature puts emphasis on teacher development as the primary step in improving student learning experiences and results. Meta-analysis of past research results on different effect sizes impacting student achievement conducted by Hattie (2012) reveals that teachers and teaching have a significant impact on student learning outcomes. With an average effect size of 0.40, teachers have the highest effect size of 0.47 and teaching of 0.43, respectively. These findings support the claim that the quality of a teacher is the single most important determinant for students' learning (Sanders 1998). Therefore, teachers' capability to organize learning and their professional development should have primary emphasis, and only then can the improvement of students' progress be addressed (Fullan 1996). Teaching as a profession is about improvement of an individual, raising the performance of the team and increasing teaching effectiveness across the whole profession (Hargreaves and Fullan 2012).

Earlier research suggests that teachers' practical knowledge is the core of their professionality. As mentioned earlier, practical knowledge is constructed by teachers in the context of their work that integrates experimental knowledge, formal knowledge and personal beliefs (Van Driel et al. 2001). Practical knowledge should be gathered through collaboration with other teachers. Improvement in teaching is believed to be a collective rather than an individual enterprise, and analysis, evaluation and experimentation in collaboration with colleagues are the conditions under which teachers improve (Rosentholtz 1991). The main message about teachers' professional growth through gathering practical knowledge should be about teachers being open to evidence of their impact on students, critiquing each other's performance in light of such evidence and forming professional judgements about how they then need to – and indeed can – influence how student learning takes place in the class (Hattie 2012).

Despite the evidence and the fact that almost every other profession conducts most of its training in real-life settings (doctors and nurses in hospitals, lawyers in courtrooms), very little teacher training takes place in teacher's own classroom, the place in which professional training would be precise and relevant enough to be most effective (Barber and Mourshed 2007). Therefore, in this study we focused teacher learning on real-life practice at school.

In order to bring about changes, teachers have to be immersed in their own and their colleagues' teaching experiences. They must analyse and reflect on these experiences. During CPD sessions, it is crucial to create learning situations that allow teachers to acquire different kinds of experiences, take part in discussions, exchange opinions and analyse and reflect on their own and their colleagues' acquired knowledge, that is, to facilitate mutual immersion. Accordingly, a system which enables teachers to learn from each other and share their best practices of teaching must be created. This means that along with the traditional hierarchical teacher in-service training patterns, different forms of further professional growth have to be sought – exchange-based models for teachers' collaboration and accumulating mutual experience. In the case of Latvia, this model implies a simultaneous process of teacher training and changing classroom practices.

There is an obvious need to develop a structure:

- That can achieve the goal of disseminating innovative ideas of teaching (IBSE, effective teaching, formative assessment, etc.)
- That is based on real-life school practice where teachers learn from each other
- Where teachers learn by collaboration, experience and exchange of ideas
- Where teachers feel their colleagues' support
- Where teachers have supportive feedback about their practices
- Where teachers can learn how to reflect
- That is coordinated but not hierarchical
- Where the activities are regularly performed

Research Methodology

Development of suitable professional learning models for various groups of teachers is needed. These must incorporate the three interrelated components of professional growth: lesson observation, reflection and collaboration.

Therefore, we pose the following research question:

How can a teacher professional learning model be implemented that develops teaching, reflection and collaboration skills?

The CPD Model

Structure of the Model

The fundamental idea of the professional learning model is to focus on teaching and observing lessons in real-life classroom environments. The model (see Fig. 13.1) allows for teachers to develop a core group of colleagues who work together in teaching, analysing and collaborating for long periods of time. By developing this core support, teachers are willing to take new risks in their classrooms, and the transfer of new methodologies occurs.

The model for teacher development is based on the philosophy that changes arise from a teacher's immersion in his/her own practice. This is facilitated by regular training of reflection skills and repeated immersion into the cycle of "observe–reflect–write–discuss". These skills are practiced several times during every workshop and repeated many times during the year, similar to the action research spiral (Kemmis and Mc Taggart 2000). Collaboration, where the teachers jointly observe and analyse lessons, lies at the basis of this model and helps improve team player skills.

Fig. 13.1 Teacher learning model

Description of the Participants

The model was implemented in 2011 within the NCE innovative experience schools collaboration network in close cooperation with the Centre for Science and Mathematics Education at the University of Latvia. One teacher team per school was selected. This article looks into two samples.

The first group included teacher teams from 22 schools representing 19 municipalities. One team (four to five people) consisted of science teachers (one each of chemistry, biology and physics), a mathematics teacher and a representative of the school administration. In total 82 teachers and 22 school administration members participated. These teachers had demonstrated active participation in the network in 2011–2013 and had already acquired inquiry-based teaching experience.

All of the participating school teams were grouped according to geographical location with schools located close to each other forming a group. As Fig. 13.2 shows, groups consist of five to six school teams (middle element of the figure). Teacher collaboration takes place in their individual school teams – a chemistry (C), biology (B), physics (P) and mathematics (M) teacher and a representative of the school administration (A) (left element of the figure). Then, collaboration takes place among teachers in the regional group (middle element of the figure). Teacher collaboration is led by expert coaches.

The second group in the research study consisted of teams from 13 schools with three participants in each – two primary school teachers and a school administration representative – making up a total of 39 participants. The collaboration model utilized by these teachers has been in operation since 2014.

Eight coaches, with coaching experience of between 5 and 15 years from the Centre for Science and Mathematics led the workshops, provided feedback and

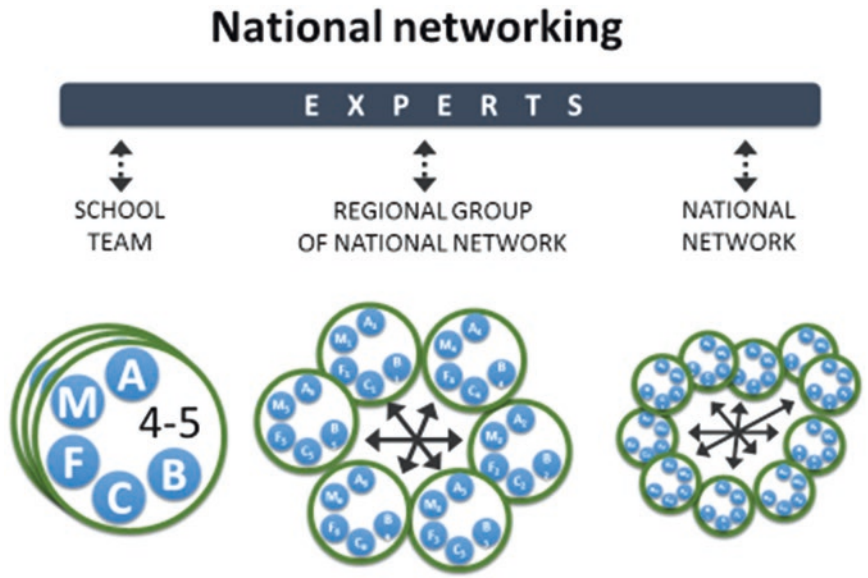


Fig. 13.2 National networking model

developed the research. In order to ensure that the expert coaches were well prepared and consistent in observations, video training and a number of live lesson observations and joint analysis of lessons were done before the research.

How the Model Works

Each school team had opportunities to learn from their colleagues, visit other schools and observe and analyse lessons. During the school year (November–April), each group of teachers from each school participated in a cycle of five or six workshops. Each day-long workshop took place in a different school and included classroom observations of lessons and joint lesson analysis, as well as informative meetings on a particular issue. The length of one workshop was six to eight sessions. Each session was 40 min long. During 1 school year, teachers participated in five to six workshops. In total, this amounted to about 40 h of professional development. The school team and the entire regional group worked together through the entire learning period of 2 school years.

New teaching and learning experience programmes for different groups of teachers were developed based on the teachers' needs. Experience showed that changes in the classroom were achieved by focusing on the theme of effective teaching in the first year of training. The following year then focused on particular teacher needs, for example, mastering scientific inquiry teaching skills. The programme also

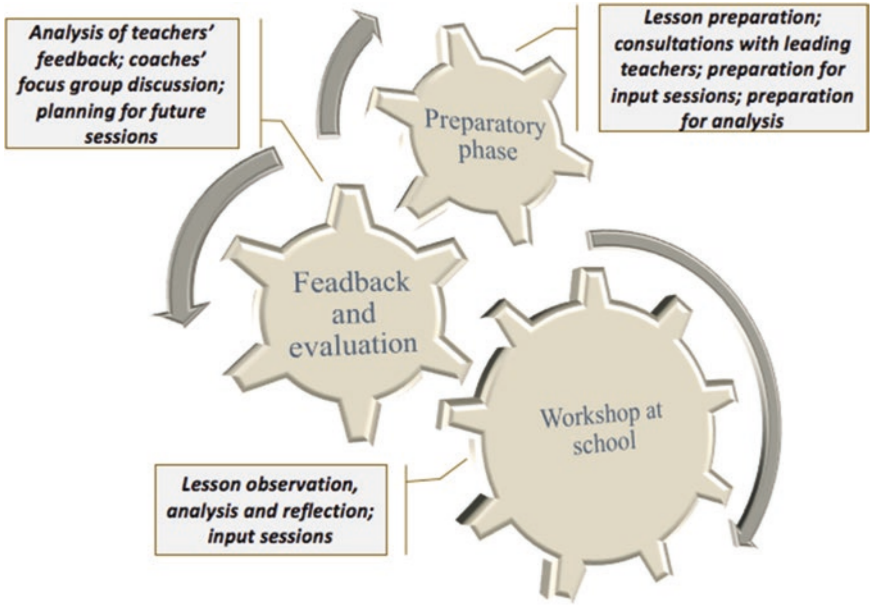


Fig. 13.3 The three-phase model

included individual teacher assignments between workshops to practice the newly acquired knowledge in their daily teaching and to prepare for the upcoming workshops. Teacher collaboration within their school group continued also between workshops.

The structure of the workshops includes three phases (see Fig. 13.3): the preparatory phase, the workshop at a school and feedback and analysis.

During the preparatory phase, coaches and the school team jointly planned the workshop, discussed the lessons to be observed and reviewed information needed for the lessons.

The workshop at a school consisted of three parts (see Fig. 13.4). During the introductory part, goals were set and any necessary information was given. The second part included joint observation of lessons. The third part was lesson analysis. The coaches supervised and gave guidance in analysing the observed lessons. During the second year of the workshops, an additional session with a particular focus on reflection was introduced. During the evaluation phase, the coaches analysed teachers' feedback.

Every participant experienced two roles: leading a classroom lesson observed by colleagues (as a leader) and as a learner – observing, analysing and reflecting on their colleagues' teaching and students' learning.

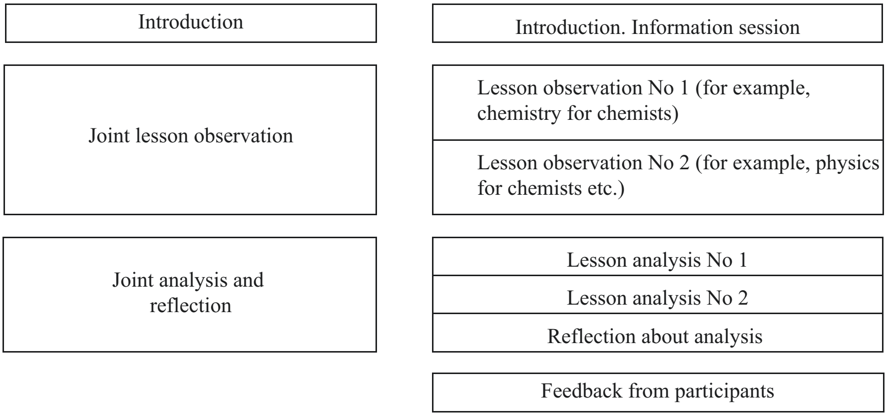


Fig. 13.4 The second phase. Structure of workshops

Sources for Data Collection

The study was conducted in Latvia. Various data sources were used in order to compare the opinions of all the involved groups (teachers, school administration representatives, expert coaches).

The impact of the workshops was analysed with the help of teacher questionnaires after the first and second years of running the model (2012, 74 respondents, Cronbach's Alpha 0.87 and 2013, 82 respondents, Cronbach's Alpha 0.94) for the first sample and for the second sample from 2015 (20 respondents, Cronbach's Alpha 0.92).

Teacher questionnaires included questions about teacher skills in conducting teaching, teacher's performance and reflection and collaboration skills and factors facilitating professional training and growth as well as support needs. For example, six questions refer to teachers' reflection skills. Respondents evaluated different aspects and effects of the collaboration model and specific benefits. All surveys asked respondents to provide their opinion according to a Likert scale 5–0, where 5 stands for "yes, agree completely" and 0 – "definitely not". Respondents could also provide comments to their answers if they wished to do so.

Teacher questionnaires were supplemented with written feedback from teachers at the end of each workshop. The responses were then coded for the purpose of analysis. Teachers gave their feedback about the perceived benefits from each information session, lesson observation and lesson analysis.

Additionally, after each workshop, a focus group of coaches was conducted, and transcripts with expert coaches' oral feedback and written transcripts were made. Transcripts from discussion groups conducted with teachers between seminars were also used. This data gave information about the teachers' professional growth and their further learning needs both from the expert coaches' and teachers' point of view.

Lastly, school administrators were surveyed. In 2013 the network participants included 22 responses. The survey was supplemented with motivation letters as part of analysis by school administration for continuing collaboration in the network as well as with structured interviews. These data sources gave information about the effects of the implemented teacher professional learning model on the school level and whether teachers' professional growth was visible from the school administration's point of view.

The reliability (Cronbach's alpha) for each questionnaire was analysed – R version 3.1.1was used.

Results

The survey of teachers and feedback from coaches and teachers all demonstrated that the model enhanced the development of teaching skills and as developed reflection and collaboration skills in both groups of teachers.

One workshop included observation and analyses of a lesson from a different subject area. This was beneficial for the participants. For example, if a chemistry teacher was observing a mathematics lesson, apart from focusing on the structure of the lesson, he/she could experience how students felt and thus provided more stimulus to change the teacher's philosophy and approach.

Teachers were actively involved in the development of the workshops, giving added value to their skills. Teachers from the network agreed that they benefited most from observation of classroom teaching and learned new methods from their colleagues' lessons.

Consequently, the most obvious gain for the teachers was the teaching and learning skills (including scientific inquiry) which they directly observed in colleagues' lessons and were able to transfer to their own classroom. In feedback, teachers wrote the following:

- *Finally I saw group work that I could learn from.*
- *I learned several "tricks" from other people that I can use in my lessons. When I lead a lesson and get feedback I often find out things I was not even aware of.*
- *I learned how to encourage pupils to think, about how to organize learning, how to encourage students' activity, how to positively evaluate and analyse the lesson.*

The teachers' 2012 survey contains testimonies such as the following: *The workshops have improved my lesson planning and leading skills, while at the same time developing students' scientific inquiry skills* (41%, completely agree; 45%, agree). Teachers often saw immediate gains from observing their colleagues' lessons, as this quote from the survey on performance in 2012/2013 illustrates:

- *I learned how to organize lessons to master particular inquiry skills before students engage in scientific modules and how to find a use for routine items in laboratory works.*

According to the survey from 2015, 88% of teachers in the second group admitted that collaboration with their colleagues helped them improve their teaching and lesson evaluation skills (evaluations of 5 and 4 on Likert scale 5–0).

According to the survey from 2012, teachers indicate that leading and analysing lessons helped them evaluate their strengths and weaknesses (62% completely agree, 30% agree) and improved their skills to reflect on their performance together with colleagues (58%, 39%). A teacher wrote in the 2012 survey*: I learned to understand what my actual knowledge and skills were and what I had assumed I knew and was able to perform.*

In the survey from 2013, 91% (evaluation 5 on Likert scale 5–0) of teachers felt they had improved their ability to accept given feedback, and 80% improved their ability to give feedback to colleagues.

Responses of the teachers from the second group in 2015 showed that 77% believed they had improved their lesson observation and analysis skills through collaboration with their colleagues (evaluation 5 on Likert scale 5–0), and 53% have perfected their reflection skills and discussion about goals of the lesson.

The following quotes from coaches' transcripts corroborate these improvements:

- *Teachers take detailed lesson observation notes in order to be able to discuss and share.*
- *Irrespective of sometimes passionate discussion, people appreciate the progress achieved through exchange of opinions and ideas. I enjoyed the discussion and I highly appreciate the openness and different views revealed during the discussion.*

According to the teachers' survey, through collaborating with their colleagues during the workshops, 77% teachers felt immersed in their professional work ("yes" – evaluation 5 on Likert scale 5–0, 2013). In addition, 71% of teachers from the second group admitted that they had improved their skills through collaboration with other teachers ("yes" – evaluation 5 on Likert scale 5–0; 2015).

The good news is that teachers developed a need to reflect on their performance and to collaborate with their colleagues. It is important to emphasize that the model combines individual reflections and group reflections. Each cycle of reflection enabled the participant to compare his/her ideas with those of his/her colleagues. Consequently, collaboration and reflection is in essence a necessary precondition for the model to succeed. At the same time, regular practice develops collaboration skills – 96% of teachers (2013) agree that participation in seminars had been extremely beneficial in this respect. Teachers admit that collaboration with colleagues enabled them to more readily share ideas and experiences (*yes* and *definitely yes* 88% – teachers from the first group – and 100% from the second group). They admit acquisition of common values (teaching philosophy) 93% and 77%, respectively, which is supported by the following quotes:

- *Lessons observation by colleagues is very helpful – they notice significant nuances that need improvement.*
- *Coaches and colleagues help me to understand whether I am going in the right direction (2015).*

Accepting teachers from other schools into their classrooms and demonstrating a lesson helped teachers to develop their leadership skills. Analyses were structured to emphasize the positive and let the teacher who is leading the demonstration lesson reach a sense of achievement as well as raise his/her self-esteem. Positive emotions and awareness of his/her performance is the only way to becoming a good leader. Survey results showed that an increasing number of teachers express a desire to become teacher leaders in their schools.

In surveys from 2013 to 2015, teachers admitted that collaboration with colleagues developed trust in mutual relationships and provided a sense of safety (*definitely yes and yes* 86% – teachers from the first group – and 82% from the second group), a sense of satisfaction and support for 89% and 88%, respectively. Eighty-nine percent in the first group and 86% in the second enjoyed positive emotions. At the same time approximately 30% of teachers from both groups admitted the presence of stress. The figure went up to 53% in cases where the particular teacher had his/her lesson observed and analysed. At the same time, 100% of teachers asserted that collaboration motivated them to improve their skills.

A teacher wrote in 2012*: Lots of stress before the demonstration lesson – it is absolutely normal and helps focus on the goal. Lesson analyses reveal the lesson from a different perspective. Colleagues often find more positive than I do myself. This is very inspiring.*

In conclusion, the model was successful for the science and mathematics teachers and can be transferred to the elementary school classroom practice.

Discussion

The research concludes that knowledge acquired in the workshops is successfully transferred to classroom practice. This is a very important achievement because traditional teacher professional training models have only a minor effect on classroom practices (Fullan 2011b).

The research shows that when a teacher has to demonstrate leadership in a lesson that is being analysed, he/she performs his/her best and transfers the knowledge to his/her practice. This is supported by the following feedback:

- *The most important gains for me were ideas and materials that I can use in my lessons* (2013).
- *I was encouraged to use more scientific inquiry in my lessons* (2013)!
- *Demonstration of best practices is really helpful – we can watch other teachers perform, and this encourages us to take over the good practices* (2015).

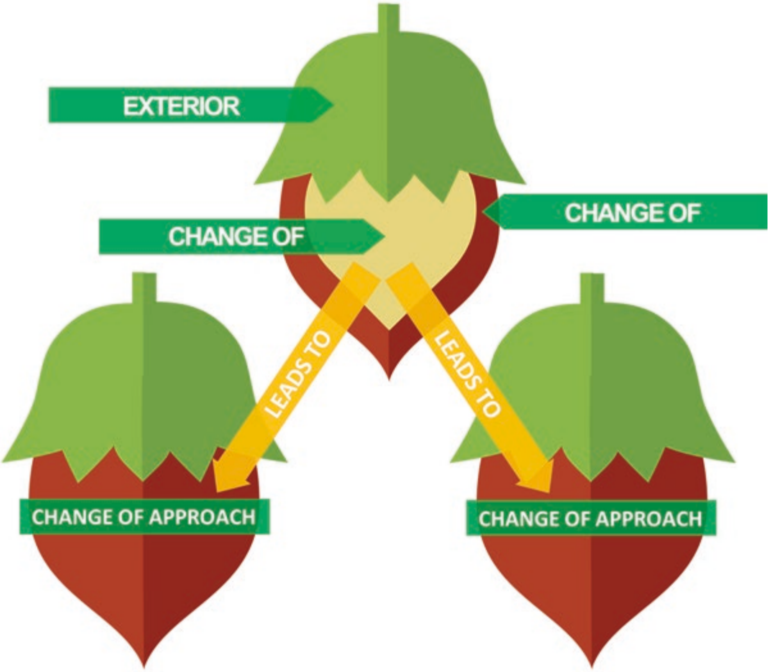


Fig. 13.5 How changes occur and disseminate – “the hazelnut model”

Our experience shows that this new professional development model helps teachers see how their colleagues apply teaching skills that the teacher himself/herself is hesitant to try. The hesitancy may arise from the lack of implementation skills, assumption that he/she is under qualified to perform or because they are unfamiliar. The new model can inspire changes in the practices of those teachers who lack familiarity with different teaching paradigms.

Long-term involvement in lesson observation workshops showed gradual changes to teaching. Reflection sessions demonstrated the change in teachers’ opinions. Deeper investigation of this change is the goal of future research.

A teacher can help his/her colleagues only when he/she has developed the confidence that that he/she has ownership of a teaching methodology and is capable of providing real assistance to others. However, the way to ownership resembles the chicken and the egg dilemma. In order to be willing to go deeper and invest more, the teachers has to at least express the desire for ownership. Figure 13.5 shows the metaphor of peeling off the shell of a hazelnut. Any exterior changes (new equipment, technology, a particular teaching method, etc.) are but the very outer layer (the green leaves around the nut that have to be removed). The hard shell of the nut is the change to the approach, but the centre – the kernel – represents the views on teaching (changes in teaching philosophy). It is here at the core where the teacher buys into a sense of ownership when he/she applies the particular skill or teaching methodologies because it has been mastered as his/her own. Having found the edible kernel of the nut makes the teacher become a leader and work with his/her colleagues on implementing changes and dissemination of a new approach or ideas. The teacher can inspire and support his/her colleagues when he/she has fully comprehended the value of the new approach, that is, the teacher has obtained ownership of it.

Deeper changes are associated with regular reflection skill training, for example, multiple practices of the "observe–reflect–write–discuss" cycle (a few times during every workshop and multiple times during the year). One teacher wrote:

> I gained new, creative ideas and benefited from the exchange of experience. I improved my lesson analysis skills and learned to see the positive things. I became aware that my way of teaching met the requirements of a modern lesson.

A number of schools have implemented collaboration and lesson-based professional training for all teachers at their schools. A school administrator wrote: *We are learning to open the classroom door, to reflect and not to be afraid if we make mistakes. We will continue to practice joint learning, collaboration lessons, observation, analyses and joint lesson leadership. We will reflect and discuss teacher progress in organizing learning in the classroom. We are certain that 10% of a teacher's work time must be allocated to efficient professional training.* This is supported by a variety of sources of literature (Barber and Mourshed 2007).

Teacher learning that results in the transfer of newly acquired knowledge to the classroom is gradual and occurs on different levels. The progress is obvious if teachers of the same group attend several years of workshops, because exposure to more practice improves their analysis and reflection skills.

Coaches' analyses of teachers' feedback indicated levels of impact the training had on the gradual development of teachers' analysis and reflection skills. At the simplest level, teachers took a particular element from an observed lesson and used it 1:1 in a similar situation in their own classroom. Moreover, upon completion of the workshop experience, the time and depth of teachers' reflection increased, and teachers' awareness of the importance of lesson analyses was deepened. At the beginning of the cycle, teachers would ask: *What is the sense of getting so detailed?* The questions were in large part the same in the middle stage: *It is all the same over and over again, it is getting boring*, and *Aren't we focusing on the same things too much?* However, at the end of the second cycle, the nature of the questions and comments had completely changed: *We ran out of time! We had no time to discuss everything we wanted*! This has been described more thoroughly in the paper "How Science Teachers Learn to Reflect by Analysing Jointly Observed Lessons" (Namsone et al. 2015).

However, implementation of the model has several limitations. At the beginning, lesson observation and analysis is taught through videos. Workshops involving real classroom lesson observation followed afterwards. Live lesson observation is extremely important as part of the change of teachers' approaches and beliefs. It enables a teacher who has never practiced a particular method to see how it is applied by his/her colleagues and then comes to believe that it can work with real students in a real school environment in his/her own classroom.

Limitations of this model for professional development are the quality of the demonstration lessons in real classrooms as well as to the stress caused by the presence of additional people in the classroom, both for the teacher and the students. The model will be successful only if there is trust among the teachers themselves and the teachers and coaches. Trust forms if the same group of coaches develop a long-term work relationship with the same group of teachers. Building relationships within the group eliminates the stress, especially over a longer period of time. A relationship of trust takes time to build. In a new group of strangers, the model may be used formally, but superficially, and thus fail to achieve the desired results.

There is another limitation related to the quality of the lessons. School team teacher collaboration during the preparatory phase should be encouraged, and coaches should be working with the teachers and consulting with them on lesson plans. A medium-quality lesson does not significantly influence analysis and reflection trainings for the participants. However, if the teacher who is leading the class fails to receive the much needed positive feedback and the sense of achievement, this will be a setback in their and their colleagues' development. An unsuccessful lesson creates a negative emotional background and may create obstacles for objective lesson analyses. Sometimes teachers identify with their colleagues' failure and thus give credibility to not changing existing methodologies.

Teachers highly value the role of coaches – their support, feedback and workshops:

- *Support is crucial, especially feedback.*
- *Methodological support and detailed analysis are most needed.* (Quotation from 2015)

However, the model will encounter serious problems if coaches lack experience and fail to work with the teachers as colleagues. The model also has practical limitations which are related to rescheduling lessons so that teachers can visit their counterparts in different schools. The problem can be resolved if the school administration understands the significance of CPD and sees real benefits from the collaboration model.

Teachers highlight the role of school administration as a factor that has a significant impact on the joint collaboration with colleagues. Understanding and interest were named crucial by 53% of the second group of teachers. Support in resolving practical problems was mentioned by 59% of the same group teachers. Results are better if school administration works as real leaders in the learning process, supporting their teachers and facilitating team collaboration within the school.

Therefore, without the support from school administration, the model is likely to fail. In Latvia, the model has been successful within the innovative experience schools network of the NCE where a school administration member is on the school team. Over a period of time, the school administrators have appreciated the benefits of the long-term gains that overcome the particularly acute difficulties of lesson rescheduling.

Conclusions

Teachers' surveys and feedback from coaches and teachers all demonstrate that this model for professional education enhances the development of teaching skills such as inquiry-based learning as well as reflection and collaboration skills.

According to the structure of the model, teacher training incorporates real practice where the teacher (*as learner* and *as reflective practitioner*) fully engages in workshops. This allows teachers to acquire new learning experiences and to collaborate and reflect on their own or their colleagues' performance. Exposure to new situations and contexts develops teachers' teaching, reflection and collaboration skills.

When a teacher has to demonstrate leadership in the lesson that is being analysed, he/she performs his/her best and transfers this knowledge to his/her practice.

Teacher learning that results in transfer to the classroom is gradual and is implemented on different levels. Any exterior changes (use of equipment, a particular teaching method, etc.) are the very upper layers of changes. Figuratively speaking, the hard shell of the hazelnut is the change of the approach, but the centre – the kernel – represents beliefs (change of teaching philosophy) or the sense of ownership when the teacher applies the particular skill or teaching approach because it has been mastered as his/her own. It is important that the model combines the individual reflection and the group reflection.

Support of the school administration and a professional team of coaches is crucial for the model. The model will be successful where there is trust among the teachers themselves, as well as among the teachers and coaches.

References

Anderson RD, Michener CP (1994) Research on science teacher education. In: Gable D (ed) Handbook of research on science teaching and learning. McMillan, New York, pp 3–44

Barber M, Mourshed M (2007) How the world's best performing school systems come out on top. McKinsey & Co. Retrieved from: http://www.smhc-cpre.org/wp-content/uploads/2008/07/how-the-worlds-best-performing-school-systems-come-out-on-top-sept-072.pdf

Bybee R, Fuchs B (2006) Preparing the 21st century workforce: a new reform in science. J Res Sci Teach 43(4):349–352

France I, Namsone D, Cakane L (2015) What research shows about mathematics teachers' learning needs: experience from Latvia. In: Society, integration, education, vol 2, pp 45–55. doi:http://dx.doi.org/10.17770/sie2015vol2.457

Fullan MG (1991) New meaning of educational change. Teachers Colleague Press, New York

Fullan MG (1996) Turning systemic thinking on its head. Phi Delta Kappan 77(6):420–423

Fullan MG (2011a) Learning is the work. Unpublished paper. Retrieved from: http://michaelfullan.ca/wp-content/uploads/2016/06/13396087260.pdf

Fullan MG (2011b) Whole system reform for innovative teaching and learning. In: Innovative teaching and learning research. Findings and implications. Retrieved from: http://www.itl-research.com/images/stories/reports/ITL%20Research%202011%20Findings%20and%20Implications%20-%20Final.pdf

Fullan M, Langworthy M (2014) A rich seam: how new pedagogies find deep learning. Pearson, London

Hargreaves A, Fullan MG (2012) Professional capital. Transforming teaching in every school. Teachers Colleague Press/Ontario Principal's Council, New York

Hattie J (2012) Visible learning for teachers. Maximizing impact of learning. Routledge, London/New York

Hofstein A, Mamlok-Naaman R (2014) Case studies on PROFILES teacher training (CPD) and ownership. In: Bolte C, Holbrook J, Mamlok-Naaman R, Rauch F (eds) Science teachers' continuous professional development in Europe. Case studies from the PROFILES project. Freie Universität Berlin, Berlin, pp 161–164

Kemmis S, McTaggart R (2000) Participatory action research. In: Denzin N, Lincoln Y (eds) Handbook of qualitative research. SAGE, London

Kozliak EI (2000) Chemical education in countries of former Soviet Union. J Chem Educ 77(7):870–875. doi:10.1021/ed077p870

Namsone D, Cakane L (2012) Experiences from Latvia – science teachers learning from other teachers to improve teaching and reflection skills. In: Bolte C, Holbrook J, Rauch F (eds) Inquiry-based science education in Europe: reflections from PROFILES project, Alpen-Adria-Universität Klagenfurt, Berlin, pp 127–129. Retrieved from https://ius.uni-klu.ac.at/misc/profiles/files/Profiles Book 2012_10.pdf

Namsone D, Cakane L, Logins J, Volkinsteine J (2012) Science teachers' learning team – a powerful tool to improve inquiry teaching and reflection skills to focus on teachers individual needs. In: Bolte C, Holbrook J, Rauch F (eds) Inquiry-based science education in Europe: reflections from PROFILES project, Freie Universität Berlin, Berlin, pp 124–126. Retrieved from https://ius.uni-klu.ac.at/misc/profiles/files/Profiles Book 2012_10.pdf

Namsone D, Cakane L, France I (2015) How science teachers learn to reflect by analyzing jointly observed lessons. LUMAT 3(2):223–236

Olson J (2003) School technology education: the search for authenticity. In: Jenkins EW (ed) Innovations in science and technology education, vol VIII. UNESCO Publishing, Paris, pp 299–323

Pavlova M, Pitt J (2003) Technology education in the Russian Federation: is the perspective clear? In: Jenkins EW (ed) Innovations in science and technology education, vol VIII. UNESCO Publishing, Paris, pp 249–276

Roehrig GH, Luft JA (2004) Constraints experienced by beginning secondary science teachers in implementing scientific inquiry lessons. Int J Sci Educ 26(1):3–24. http://dx.doi.org/10.1080/0950069022000070261

Rosentholtz SI (1991) Teachers workplace: the social organization of schools. Longman group, Harlow

Sanders WL (1998) Value-added assessment. Sch Adm 55(11):24–32

Sanger MJ, Brincks EL, Phelps AJ, Pak MS, Lyovkin AN (2001) A comparison of secondary chemistry courses and chemistry teachers preparation programs in Iowa and Sant Petersburg, Russia. J Chem Educ 78(9):1275–1280. doi:10.1021/ed078p1275

Van Driel J, Beijaard D, Verloop N (2001) Professional development and reform in science education: the role of teachers' practical knowledge. J Res Sci Teach 38(2):137–158. doi:10.1002/1098-2736(200102)38:2<137::AID-TEA1001>3.0.CO;2-U

Volkinsteine J, Namsone D, Cakane L (2014a) Latvian chemistry teachers' skills to organize student scientific inquiry. Probl Educ 21st Century 59:86–98

Volkinsteine J, Namsone D, Logins J (2014b) Teachers' learning team as a tool to improve scientific inquiry teaching. In: Bolte C, Holbrook J, Mamlok-Naaman R, Rauch F (eds) Enhancing inquiry-based science education and teachers' continuous professional development in Europe: insights and reflections on the PROFILES project and other projects funded by the European Commission. Berlin, Klangenfurt, pp 157–161

Chapter 14
Pedagogical Content Knowledge Development in Experienced Biology Teachers in Their First Attempts at Teaching a New Topic

Kennedy Kam Ho Chan and Benny Hin Wai Yung

Abstract It is not uncommon for teachers to be required to teach new content due to curriculum changes or shifts in teaching assignments. The former is particularly the case for science teachers because of the advancement in science. However, there is little research on how experienced teachers may develop the requisite knowledge for teaching new topics that they have never taught before. Hence, we explored how six experienced biology teachers prepared for and enacted their first-time teaching of a new topic, polymerase chain reaction, in the context of a curriculum change. Pedagogical content knowledge (PCK) was used as the lens to examine the teachers' development of topic-specific knowledge. In this chapter, we aim (1) to illustrate how new PCK development can be facilitated by a teacher's disposition to enact two pedagogical moves, namely, conducting subject matter analysis and assessing students formatively, and (2) to characterise the instances in which the teachers invented new instructional strategies/representations during the interactive phase of the lesson (i.e. on-site PCK development). The mechanism of on-site PCK development as a three-step process is also proposed. Implications on teacher professional development arising from the findings are discussed.

Introduction

It is not uncommon for teachers to be required to teach new content due to curriculum changes or shifts in teaching assignments. Owing to the evolving and expanding nature of scientific knowledge, the need for science teachers to teach a new body of content is arguably more common (Finlayson et al. 1998). While many studies have investigated the knowledge bases of novice teachers and their development in their attempts to teach a new topic (e.g. de Jong et al. 2005; Lee et al. 2007), these studies rarely extend to experienced teachers. This chapter documents our attempt

---

K.K.H. Chan (✉) • B.H.W. Yung
The University of Hong Kong, Pokfulam, Hong Kong
e-mail: kennedyckh@hku.hk

J. Yeo et al. (eds.), *Science Education Research and Practice in Asia-Pacific and Beyond*, DOI 10.1007/978-981-10-5149-4_14

to investigate how experienced biology teachers developed new professional knowledge in their first-time teaching of a new topic in the context of curriculum changes in Hong Kong. We also examined the contributing factors involved in new knowledge development, be it during the planning stage, interactive phase of the lesson or during post-lesson reflection. Such information has implications on how to prepare teachers to cope with the continual demands of teaching new topics in a changing world and/or changing curriculum.

Literature Review

In the following sections, we first discuss the framework we used to investigate teacher knowledge. We then describe how the existing literature informed our study.

Pedagogical Content Knowledge

Shulman (1986, 1987), in his seminal articles, put forward the construct of pedagogical content knowledge (PCK), which he conceptualised as "subject matter knowledge *for teaching*" (p. 9). This unique province of knowledge for teachers is an amalgam of content knowledge and pedagogical knowledge (PK) that enables teachers to "transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students" (Shulman 1987, p. 15). PCK has been widely used as a theoretical lens for researching the professional knowledge of science teachers (Abell 2008). In this study, we investigated teachers' personal PCK, which encompasses teachers' "knowledge base used in planning for and the delivery of topic-specific instruction in a very specific context" (Gess-Newsome 2015, pp. 30–31). In line with the PCK consensus model, we view PCK as concerning the teaching of a *particular* topic (i.e. PCK is topic specific) (Gess-Newsome 2015). Hence, when teachers need to teach a new science topic, they need to develop new topic-specific PCK.

Although PCK has been conceptualised in various ways by different scholars, there are two knowledge components common in all the PCK models (van Driel et al. 1998). They are (1) knowledge of instructional strategies and representations (KISR) and (2) knowledge of students (KS). Based on Magnusson et al. (1999), KISR refers to teachers' topic-specific knowledge and understanding of specific strategies and representations that are useful for helping students comprehend specific science concepts, while KS pertains to teachers' knowledge and understanding of requirements for learning specific science concepts and areas of science that students find difficult. In the context of teaching a new and conceptually difficult-to-understand topic for the first time, as it is the case for the present study, it is highly likely that teachers need to develop new KISR to make the otherwise difficult science concepts accessible to students.

Pedagogical Content Knowledge Development

PCK development has been conceptualised in different ways. Some PCK scholars (e.g. Hashweh 2005; McNicholl et al. 2013) view it as an *inventive* process in which teachers develop new insights and repertoires of teaching the topic. Hashweh (2005), for example, suggests that PCK represents recollection of "cases of repeated experiences of teaching a familiar topic" (p. 289) by the teachers, and new PCK develops when they construct a new analogy for explaining a difficult concept. From this perspective, PCK development pertains to the expansion and elaboration of an existing knowledge base or put simply repertoire enrichment. Others view PCK development as an *integrative* process in which teachers draw on their PCK in a more integrative manner (e.g. Marks (1990); Park and Chen (2012)). For instance, Park and Chen (2012) first identified the PCK components drawn on by the teachers in their study in their different teaching episodes and then constructed PCK maps to showcase the integration of the teachers' PCK. Still others regard PCK development as a knowledge *refinement* process (e.g. Gess-Newsome et al. in press; Lee et al. 2007). For example, Gess-Newsome et al. (in press) used a four-level rubrics to assess the quality of PCK of the teachers. They rated the teachers' PCK as limited, basic, proficient or advanced based on the appropriateness, the pedagogical effectiveness and the accuracy of the instructional strategies/representations. In this approach, PCK development refers to a better quality of knowledge.

No matter how PCK development is conceptualised, experience and reflection are the foundations for PCK development (Nilsson 2008). PCK development occurs in the context of planning, teaching and reteaching a particular topic (Hashweh 2005; Magnusson et al. 1999) when teachers reflect in real time *during* the act of teaching (i.e. reflection in action) and *after* instruction (i.e. reflection on action) (Schön 1983, 1987). In the present study, we elicited the teachers' pedagogical reasoning underpinning their planning to teach the new topic and unpacked their reflection in action and reflection on action with the goal of understanding how they may develop new PCK in the context of teaching a new science topic. We focused on instances in which teachers *invented* new KISR. Through analysing these instances, we hoped to identify factors that can support new PCK development.

Pedagogical Content Knowledge in Experienced Teachers

While there is a plethora of studies on novice teachers' PCK/PCK development, similar studies seldom extend to experienced teachers (see the review by Schneider and Plasman 2011). The voluminous literature on how novice teachers develop PCK suggests that novice teachers are unable to develop PCK in their initial attempts at teaching a new topic even if they possess adequate subject matter knowledge (SMK) of the new topic (e.g. Lee et al. 2007). Novice teachers' PCK development is often found to be limited by their weak PK and/or poor emotional attributes (e.g. Davis et al. 2006). Under such condition, it is unlikely to detect any PCK development in the context of teaching a new topic, not to mention an investigation of the facilitative factors involved. Hence, we shifted our focus to studying experienced teachers.

Some studies investigated the differences between novice and experienced teachers' PCK (e.g. Clermont et al. 1994; Geddis et al. 1993). This strand of research suggests that experienced teachers have often amassed a wealth of PCK as a result of repeatedly teaching a particular topic. Although these studies often indicate a gap between the PCK of experienced teachers and that of novice teachers, researchers have yet to illuminate *how* and *why* PCK development occurs in the experienced teachers.

Another line of studies examined how experienced teachers teach a new topic that is conceptually *unfamiliar* to them. As a result of their lack of SMK of the new topics, these teachers often developed limited new PCK in their initial attempts to teach the new topic. A representative is a study by Sanders et al. (1993) who capitalised on a natural setting in which three experienced teachers were required to teach topics *outside* their certification area. The experienced biology teachers in the study were unable to transfer their expert teaching behaviours when confronted to teach an astronomy topic, and they could only teach at a "novice" level (Sanders et al. 1993). They displayed difficulties in predicting students' difficulties (i.e. developing new KS) and selecting appropriate strategies for representing the key ideas (i.e. developing new KISR) of the topic. Collectively, studies in this research strand do not say much on how experienced teachers may develop new PCK and the facilitative factors involved.

To sum up, the above review points to (1) the need for a closer look at how experienced teachers may develop new PCK and (2) the advantages of studying experienced teachers *within* the subject specialisation (i.e. the new topic is within their subject specialisation). Compared with their counterparts outside the subject specialisation, these teachers should be less likely limited their SMK while drawing on their prior teaching experiences to develop new PCK. We also situated our study in the teachers' first attempts at teaching the new topic such that their prior PCK for teaching the new topic was little or none (Loughran et al. 2006). Under such circumstances, it would be more likely for the experienced teachers to *invent* new instructional strategies/representations and hence a more conducive setting for answering the research questions, as delineated below.

Research Questions

In the larger study, the overarching research question is: How and why does PCK development occur in experienced teachers in their first attempts to teach a new topic? Due to space, we limit to the following two questions in this chapter:

1. What are the major factors that facilitated the development of new PCK of the case teacher who developed the richest PCK among the participants?
2. How do experienced teachers develop new PCK on the spot of a lesson?

Methods

Research Approach

The reported findings come from the data of a larger study involving six experienced teachers (all in pseudonym; see Table 14.1 for their background). The study adopted a multiple case study approach (Merriam 1998) and was naturalistic in nature. It adopted an interpretive paradigm, focusing on "the immediate and local meanings of actions, as defined from the actors' point of view" (Erickson 1985, p. 119). That is, it aimed at finding out, from the perspectives of the actors (the case teachers), why they acted in a particular way when coping with teaching a new topic in light of a curriculum change.

Research Context

The study was situated in the context of implementing the new senior secondary (NSS) curriculum in Hong Kong. It was conducted when the teachers were teaching their first cohort of NSS secondary six (S6) students (age 17–18) the topic polymerase chain reaction (PCR) for the *first* time.

Data Collection and Analysis

In the larger study, data were collected from multiple data sources including classroom observations (37 lessons), field notes, classroom artefacts and in-depth semi-structured interviews (83 interviews) to capture how teachers' PCK developed in their first attempts to teach the new topic, PCR. In the first stage of our analysis, we analysed how the teachers developed new PCK and the factors involved. To achieve this goal, we first constructed vignettes (51 vignettes with each containing multiple verbatim quotes and relevant classroom transactions) documenting how the teachers taught key ideas of the topic in the lessons where the teachers taught

Table 14.1 Information of the participating teachers

Name	Gender	Education	Science background	Teaching years
Alex	Male	B.Sc/M.Phil/M.Sc	Biochemistry	14
Brandon	Male	B.Sc/M.Ed	Biology	23
Chris	Male	B.Sc/M.Phil	Biochemistry	6
Dennis	Male	B.Sc/M.Sc	Biology	8
Eric	Male	B.Sc/M.Ed	Biochemistry	17
Felix	Male	B.Sc/M.Phil	Biology	5

similar subject matter. Following a method similar to that of Park and Chen (2012), a PCK reporting table was constructed for each vignette that included a detailed description of the relevant classroom events, including (1) what the teacher and students did, (2) evidence of PCK components and (3) what components of PCK were integrated. Codes were developed based on the four topic-specific PCK components in the Magnusson et al. (1999)'s model (i.e. knowledge of curriculum (KC), knowledge of assessment (KA), KISR and KS). An example of such a PCK reporting table can be found in Appendix. The detailed coding and how the data were triangulated using multiple data sources (i.e. video transcript, interview transcript) during the construction of the PCK reporting tables and the vignettes can be found in Chan and Yung (2015). The major factors influencing the PCK development were identified in each of the vignettes. For each vignette, a figure, where appropriate, was constructed to illustrate how the teachers' PCK developed from the lesson planning, through the interactive to the post-lesson reflection phases of the lesson (see Figs. 14.1 and 14.2) and the factors involved.

As the data emerged, we came to notice that there were instances in which teachers developed new KISR during the interactive phase of the lesson (thereafter operationally defined as on-site PCK development). We further unpacked the reflection in action (Park and Oliver 2008b) associated with on-site PCK development by analysing the teachers' reconstructed thought processes (through post-lesson interviews). The whole data set was re-examined for more instances of on-site PCK development. The number of instances of on-site PCK development, the total pieces of KISR developed and the types of instructional strategies/representations (e.g. analogies, illustrations, etc.) were described in Table 14.2. They analysed and then focused on (1) the stimulus that invoked on-site PCK development and (2) the factors contributing to that development in each of the teaching vignettes. Further details can be found in Chan and Yung (2015).

The trustworthiness of the findings was ensured through triangulation of multiple data sources, checking of coding reliability between the two authors and member checking of the findings by the teachers involved.

Results and Findings

In the following sections, we address the first research question by reporting the findings of a case teacher, Alex, who developed the richest PCK among the six teachers investigated. We then summarise our findings from the larger studies in relation to the second research questions. Each summary is followed by a vignette which serves to illustrate our findings. To ease readers' burden of understanding the scientific concepts being taught, the two vignettes chosen revolve around teaching of the same concept, namely, the functions of primers in PCR. Before presenting the vignettes, the following gives a conceptual context to aid readers' understanding.

Table 14.2 Occurrence of on-site PCK development in this study

Participant	No. of lessons videotaped	Type of instructional strategies and representations				Total no. of instances of on-site PCK development	Total no. of pieces of KISR developed
		Illustrations	Examples	Analogies	Others		
Alex	10	1	1	0	2	3	4
Brandon	11	0	1	1	0	2	2
Chris	7	0	2	0	1	2	3
Dennis	2	1	1	1	0	2	3
Eric	3	0	0	0	0	0	0
Felix	4	0	0	0	0	0	0

Conceptual Background

PCR is a molecular technique which allows the *selective* amplification of a specific fragment of DNA from a larger mass of DNA. The PCR process consists of three repeated steps, one of which is the annealing (i.e. sticking) of primers to the DNA to be amplified. Primers are short chains of polynucleotides which bind to specific regions of the DNA strands for amplification. They serve as a starting site for the enzyme, DNA polymerase, to carry out its function (i.e. DNA synthesis). They also serve as a "marker" to define the exact region of the DNA fragment for amplification in the PCR process.

Major Factor Contributing to Alex's PCK Development

Among the six teachers, Alex developed the richest PCK for teaching the new topic. A major facilitating factor was his disposition to enact two pedagogical moves in the lesson planning phase, namely, subject matter analysis and assessing students formatively. These two pedagogical moves enabled Alex to capitalise on his wealth of SMK to develop new PCK. The following vignette illustrates *how* the two pedagogical moves acted to facilitate new PCK.

Vignette 1 Compared to other teachers participating in the study, Alex adopted a rather unique approach in his lesson planning (for details, see Chan & Yung (in press)). Below is his description of how he planned to teach the new topic, PCR:

> If they (i.e. students) don't have the pre-requisite knowledge, it is not possible to teach (them for understanding). … In short, I would try to consider two things (in relation to the content knowledge), what they have grasped and what may be difficult for them to grasp. (Entry Interview)

It is clear from above that in planning to teach a topic, Alex would analyse the subject matter of the topic carefully to identify the prerequisite knowledge for learning the new concepts. From there, he would consider students' prior knowledge and predict their potential learning difficulties. Alex mentioned how the identification of student difficulties would inform his teaching:

> [T]his is my **habit**, especially for new topics, I would think in this way. I will think from a student perspective – what mistakes they may commit. I will focus on these mistakes in planning my lessons. (Pre-Lesson Interview #1)

In the lesson planning stage, following his *habit* of analysing the subject matter, Alex first identified the prerequisite knowledge that students would need in order to understand the function of primers. He then further predicted the difficulties they would encounter in learning the new topic:

> For the functions of primers, the textbooks seldom mention the concept that PCR is for selective amplification of a specific DNA fragment. This is a gap that students may not understand why a primer is needed. … Knowledge about the mechanism of DNA replication is needed to understand how the primers function. However, students are not required to know the mechanism of DNA replication in the new syllabus. (Pre-Lesson Interview #1)

Based on the above analysis (which was informed by his knowledge of the curriculum, i.e. KC), Alex predicted that his students would have difficulties understanding the functions of primers due to their lack of prerequisite knowledge (i.e. mechanism of DNA replication) for learning the new concept. As a result of his identification of students' potential difficulties in learning the new topic (i.e. KS), he then planned various instructional strategies (e.g. using the example of amplifying an insulin gene, using a calculation task to explain why primers allow selective amplification of DNA) to make the concepts related to the function of primers more accessible to his students. To summarise, by carefully analysing the subject matter knowledge, Alex developed new KS which, in turn, stimulated him to develop new KISR for teaching the new topic.

Throughout the course of lesson planning, Alex was also mindful of embedding assessments in the course of his teaching such that he could obtain data and feedback for timely adjustment of his teaching.

Indeed, from the specific questions he set in the pop quiz (i.e. his KA), Alex found that his students did not quite understand a specific concept related to primers, as he put it in the post-lesson interview:

> This question about whether primers should be designed in a pair is problematic to students. I talked about that, though not in a very detailed manner, in the last lesson. … It is a bit unexpected to find that they were not able to answer the question. … That's why I had designed a diagram of DNA to show them concretely where the two primers are in the double-stranded DNA [on my PPT slide in today's lesson]. (Post-lesson Interview #2)

As a result of noticing and reflecting upon this "unexpected" student learning difficulty (i.e. KS) through interpreting the assessment data that he purposely collected in the lesson, Alex was stimulated to follow up the case in the next lesson by using a diagram created by himself (i.e. KISR) to explain the concept again. In short, Alex's KISR was stimulated to grow as a result of the new KS that he had acquired recently.

To sum up, Alex's disposition to enact the two pedagogical moves (i.e. subject matter analysis and designing formative assessments) in the lesson planning phase

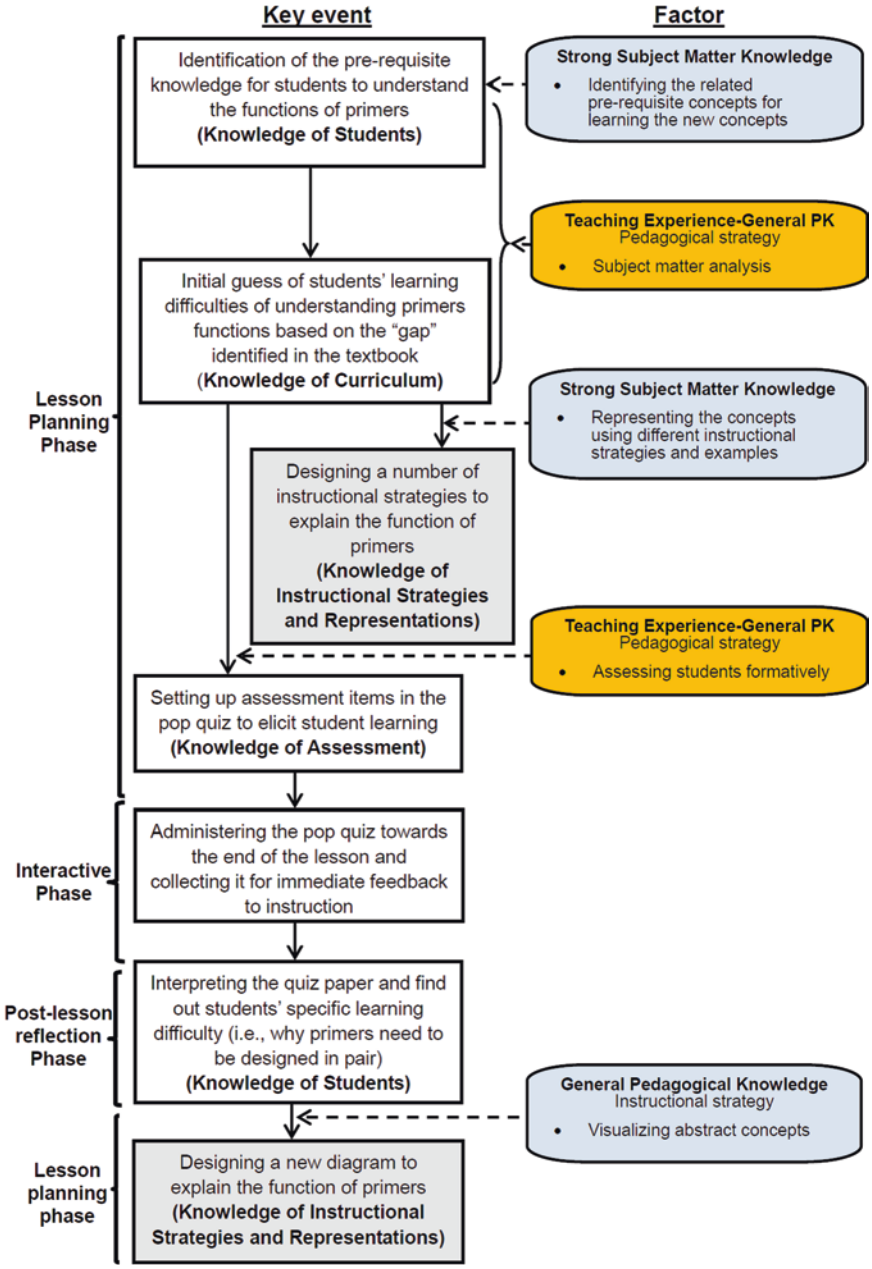


Fig. 14.1 Alex's instances of the development of new KISR in Vignette 1

facilitated his PCK development. The major events related to the instances of the development of new KISR (grey boxes) described in the vignette are summarised in Fig. 14.1.

On-Site PCK Development

In the larger study, we identified a total of nine instances of on-site development PCK from the 37 lessons videotaped (Table 14.2). There were three possible types of stimulus that triggered on-site PCK development. These included (1) unexpected student responses, (2) environmental stimuli, and (3) unanticipated student questions. The vignette from Brandon below exemplifies how on-site PCK development may take place. For other examples, please refer to Chan and Yung (2015).

Vignette 2 Brandon taught the function of primer in directing the primers to start DNA synthesis at specific location in a didactic manner in his first lesson. He revisited the concept in the second lesson. However, as revealed in the post-lesson interview, Brandon noticed that students did not "seem to understand based on his observation of their facial expressions". Hence, he invented a new analogy to make the concept more accessible to his students (i.e. KISR) on the fly of the lesson.

B: Primer acts like an initiation point. When its position is recognised by the DNA polymerase, it starts (the DNA synthesis). In the athletic meet, do you know where you should start running for the 100 m race in the field track?

…

B: It is easier to locate the (starting) position for 100 m race and 200 m race. How about that for 1500 m race?

S1: At the position for 200 m race.

B: Is it really that 1500 m race starts at the position line for 200 m race?

Ss: Inaudible

B: Where should it be? It should be near the position for 300 m race. How do you know that you're standing at (the starting position for) 300 m race. Actually, what do you rely on (to know the starting position)?

S2: Someone would tell you!

B: Besides that there is a track judge. Primer is a chemical substance. It is actually some short DNA fragment. It would anneal to the (DNA) template. Then, the DNA polymerase and the following nucleotides for making the (new) DNA would recognise that point as the starting point and "line up" there.

….

B: The primers would anneal to a specific location (of the DNA to be amplified). It is like the track judge. Depending on whether you go for 100 m race, 200 m race or 1500 m race, the track judge would lead you to the specific location (in the field track).

(Lesson Transcript #2)

Above, Brandon was equating a primer as a track judge in a track event of an athletic meet (transcript lines 14 and 19–21). The position of track judge indicates the location of the starting position for the runners to line up for the sprint events. This is similar to the role of primer in dictating the starting position for the DNA polymerase and subsequently the nucleotides to be added to the growing DNA strand. Brandon recalled why he was stimulated to transform his understanding of the role of primer into an analogy:

> The competition (analogy) was just off my head. … At that moment, I think they were confused. Primer is a DNA fragment that anneals to the DNA. When annealed, the DNA polymerase and nucleotides would start to work (on DNA synthesis). … The analogy was used to make the ideas concrete. … I really didn't think about this (confusion) yesterday as I had taught them this (idea) yesterday (in the lesson). (Post-lesson Interview #2)

It seems that the *stimulus* that triggered the development of new KISR (i.e. on-site PCK development) was student confusions (i.e. in the category unexpected student response). The teacher then retrieved an example from students' daily life (i.e. their experience in athletic meets) based on his general knowledge of students. Moreover, the invention process was facilitated by some general pedagogical strategies Brandon often employs in his teaching, as evident from the following quotes:

> I will see whether there are some daily life examples so that they can imagine the ideas more easily. (Pre-lesson Interview #1)

> I think students would be more able to understand with analogy. … It's quite frequent for me to use analogies (in my teaching). (Post-lesson Interview #2)

In other words, the *integration* process was also supported by his existing pedagogical knowledge (i.e. his preference in using analogies to make abstract ideas concrete in his teaching and the use of daily life examples). The *response* was the invention of a new analogy to talk about the concepts about the function of primers (see Fig. 14.2). Together with other vignettes from the larger study (see Chan and Yung 2015), a three-step process comprising a stimulus, an integration process and a response was proposed as a mechanism to account for the on-site PCK development observed among the teachers.

Discussion

This chapter reports on the findings from a larger study which investigated how six experienced teachers developed PCK for teaching a new science topic *within* their subject specialisation. This study responded to the recent call by van Driel et al. (2014), in their comprehensive review of PCK studies, for more PCK studies with a classroom teaching component focusing on "how teachers use their SMK in interaction with students, and how PCK develops in such a context as mediated by the teachers' PK" (p. 866). In the following, we discuss our major findings in relation to the existing PCK scholarship and discuss implications on teacher professional development arising from our findings.

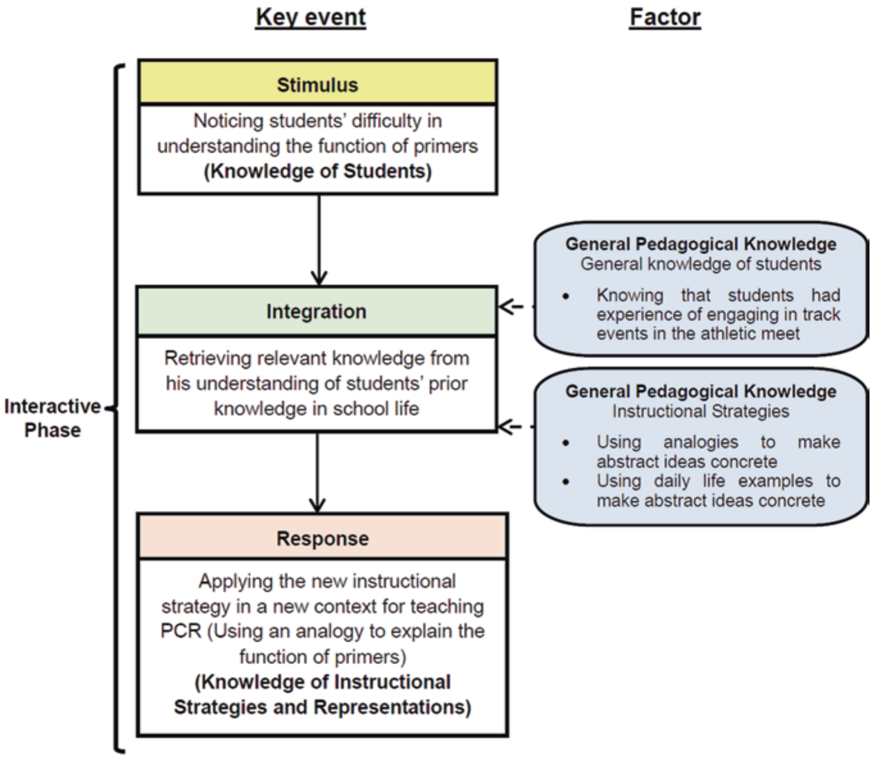


Fig. 14.2 Brandon's instance of on-site PCK development in Vignette 2

Prior PCK studies on experienced teachers rarely documented the pedagogical moves/PK that experienced teachers may employ/draw on to develop new PCK. In our investigations of instances of how the teachers developed new KISR, we described how two pedagogical moves facilitated Alex's new KISR development. By carefully analysing the subject matter in the lesson planning stage, Alex drew on his understanding about students' prior knowledge (i.e. KC and KS) in relation to the prerequisite knowledge needed to learn the new concepts (Vignette 1). This, in turn, allowed Alex to identify students' potential learning difficulties (i.e. KS) which, then, led to the development of instructional strategies/representations to tackle the student learning difficulties (i.e. development of new KISR). In other words, Alex's PCK started to develop in the lesson planning phase as subject matter analysis led to the integration of KS/KC with KISR. Alex also deliberately designed specific assessment items to gauge students' learning (i.e. his KA). Interpretation of student assessment data further informed his understanding of student difficulties (i.e. new KS) in the post-lesson reflection phase and stimulated new KISR development. In sum, Alex's disposition to purposefully enact the two pedagogical moves in the lesson planning stage not only stimulated new KISR development but also promoted PCK development in terms of the integration of PCK components (i.e. KA, KS and KISR). For more details, please refer to Chan and Yung (in press).

Some PCK studies have previously demonstrated how teachers' reflection *on* or *in* actual teaching experience of the topic may lead to development of new KS (e.g. de Jong and van Driel 2004; de Jong et al. 2005; van Driel et al. 2002). Others have also provided evidence on how teachers' reflection *in* or *on* action may stimulate *integration* of PCK components (e.g. Park and Oliver 2008a, b). Whether and how teachers may develop new KISR in the interactive phase of teaching remains under-researched (i.e. on-site PCK development). What is known from prior studies is that on-site PCK development is challenging (e.g. McDuffie (2004); Sanders et al. (1993)), and this applies to the experienced teachers in Sanders et al. (1993)'s study when they were teaching a new and conceptually *unfamiliar* topic. The present study adopted a more in-depth approach, not only does it confirm that the experienced biology teachers were able to invent new instructional strategies/representations on the fly of a lesson. Examining teachers' reconstructed thought processes associated with successful instances of on-site PCK development similar to that in Vignette 2 also allowed the current study to propose a mechanism for the knowledge creation process. A three-step process comprising a stimulus, an integration process and a response was advanced to explain the on-site PCK development observed among the teachers.

Our findings have implications for teacher professional development. First, our data suggests that Alex seemed to be able to make good use of his SMK to develop new PCK as a result of his commitments or in his own words, his *habits*— in adopting the two pedagogical moves in the lesson planning stage. This finding lends credence to the importance of developing in teachers a general mental framework for approaching the teaching of new content in addition to sharpening their SMK and PK. This would help focus teachers' attention on pedagogical moves conducive to PCK development (e.g. among others, the two identified in the present study). This recommendation is in line with recent calls for using a PCK framework to scaffold teachers' lesson planning and to structure their reflections in a *purposeful* manner so as to initialise and frame their attention to important aspects of teaching (e.g. Bertram and Loughran 2012; Hume and Berry 2011); the prime goal of which is to assist their *future* PCK development. Alex's case points to the promise of the "PCK approach" by providing empirical evidence of the powerfulness of a mental framework and its role in helping him develop PCK for teaching the new topic.

In addition, we believe that the benefits of "PCK approach" can be augmented by sensitising teachers to the idea of on-site PCK development. As a matter of fact, researchers in mathematics education have already been paying close attention to how PCK is deployed by teachers in critical moments of their teaching (e.g. Rowland et al. 2005). Some have begun designing theoretical tools (Turner and Rowland 2011) to help focus pre-service teachers' attention and reflection on critical moments of their own teaching to enhance their PCK development. We believe that sensitising teachers to the concept of on-site PCK development can serve similar benefits as this will encourage teachers to reflect on the instructional strategies/representations they invent on-site during the lessons. We would argue that only with such an awareness and sensitivity would there be a greater opportunity for valuable creation of professional knowledge of this sort be retained in the teachers' future instructional repertoires. Otherwise, it may easily be slipped through the mind of busy teachers nowadays. In sum, not only do we echo with Nilsson (2008)'s alert that experience and reflection are foundations for PCK development. We argue that the "experience" should include instances of on-site PCK development and that teachers need to be sensitised on this. Although prior studies found that it can be challenging for novice teachers to improvise and adjust their instructions on the spot of the lessons (e.g. McDuffie 2004; Gotwals and Birmingham 2016), future studies may investigate how on-site PCK development can be promoted in novice teachers through targeted intervention aiming at enhancing the factors facilitative to on-site PCK development identified in the present study.

In closing, we acknowledge the limitations of this study which include the use of qualitative case study approach. We do not wish to make generalisations about the development of PCK in experienced teachers. Rather, we wish to make use of the cases to illuminate possible facilitative factors for PCK development. Thus far, the findings may only be applicable to experienced teachers who possess the disposition to enact the two pedagogical moves described in this study, namely, conducting subject matter analysis and assessing students formatively. We also acknowledge two limitations in our methodology in the investigation of on-site PCK development. These include the reliance on teachers' retrospective reports of their own thinking and the possible post hoc rationalisation of their own teaching behaviours. Despite the above limitations, we believe that our study represents a rare, but important, attempt in investigating how experienced teachers developed new PCK in the context of teaching a new topic. Its findings shed light on teacher professional development on how to better prepare them to teach new topics, be it due to curriculum reforms or shifts in teaching assignments, both of which seem unavoidable in a teaching career.

Notes

This chapter reports the dissertation work of the first author; more detailed report of the findings can be found in Chan and Yung (2015, in press).

Appendix

Teacher	Brandon
Lesson	Lesson 2
Theme	(2) Primers and annealing of primers
Vignette	B. The function of primers II
Analysis	
What did the teacher do?	**Data sources**
In the second lesson, the teacher used an analogy he invented on the spot of the lesson to explain the functions of primers (i.e. to provide a starting site for the synthesis of DNA), when revisiting the important concepts taught in the first lesson.	Observation Field notes Lesson transcript Pre-lesson interview Post-lesson interview Stimulated recall interview
Description of student-teacher interaction	
B:	Primer acts like an initiation point. When its position is recognised by the DNA polymerase, it starts (the DNA synthesis). In the athletic meet, do you know where you should start running for the 100 m race in the field track?
Ss:	Inaudible
B:	Where should you start running for the 200 m race?
Ss:	Inaudible
B:	How about running for the 400 m race? Do you also know that? For 1500 m race, where should you start running? It is easier to locate the (starting) position for 100 m race and 200 m race. How about that for 1500 m race?
S1:	At the position for 200 m race.
B:	Is it really that 1500 m race starts at the position line for 200 m race?
Ss:	Inaudible
B:	Where should it be? It should be near the position for 300 m race. How do you know that you're standing at (the starting position for) 300 m race. Actually, what do you rely on (to know the starting position)?
S2:	Someone would tell you!
B:	Besides that, there is a track judge. Primer is a chemical substance. It is actually some short DNA fragment. It would anneal to the (DNA) template. Then, the DNA polymerase and the following nucleotides for making the (new) DNA would recognise that point as the starting point and "line up" there.
	….
B:	After the DNA has separated into two strands, what would happen? The process is called primer annealing. The primers would anneal to a specific location (of the DNA to be amplified). It is like the track judge. Depending on whether you go for 100 m race, 200 m race or 1500 m race, the track judge would lead you to the specific location (in the field track) (Lesson Transcript #2).

PCK components integrated in the episode				**Data sources**
Knowledge of Students	Knowledge of instructional strategies	Knowledge of assessment	Knowledge of curriculum	Observation
				Field notes
				Lesson transcript
✓	✓			Pre-lesson interview
				Post-lesson interview
				Stimulated recall interview

Evidence of the presence of PCK components identified in the episode	Data sources
The concepts about primer are a bit more difficult. They don't know what a primer is. I think the ideas about primer are the more problematic part (Post-lesson interview #1) (knowledge of students)	Post-lesson interviews Stimulated recall interview
I thought I was not teaching the ideas about primers well yesterday. The primers provide a starting point (for the DNA polymerase to start DNA synthesis). What is the meaning of a starting point? Different primers provide different starting points (along the DNA to be amplified). I, then, thought about how to express the ideas at that moment. … The competition (analogy) was just off my head. … At that moment, I think they were confused. Primer is a DNA fragment that anneals to the DNA. When annealed, the DNA polymerase and nucleotides would start to work (on DNA synthesis). … The analogy was used to make the ideas concrete. … I really didn't think about this (confusion) yesterday as I had taught them this (idea) yesterday (in the lesson) (Post-lesson interview #2) (knowledge of instructional strategies, knowledge of students)	
I felt that they were not able to follow (the ideas I was teaching) from their facial expression. … Then, I started to think about how to make the ideas easier. Many students studied PE (physical education). … When they (students) have field events, they know where the starting position for the 100 m, 200 m and 400 m sprints is (in the field, respectively). So, I used this analogy to talk about the concepts (Stimulated recall interview) (knowledge of instructional strategies)	
I just observed their faces. … At that interaction, I think they don't seem to understand (the idea about the primers). The concept is about recognising the location (by the DNA polymerase) and that the DNA strand extends from that position. … I thought about their daily life experiences. At that moment, I thought that running may be related to this idea. I think that running is something that they have experienced (Stimulated recall interview) (knowledge of instructional strategies, knowledge of students)	

References

Abell SK (2008) Twenty years later: does pedagogical content knowledge remain a useful idea? Int J Sci Educ 30(10):1405–1416

Bertram A, Loughran J (2012) Science teachers' views on CoRes and PaP-eRs as a framework for articulating and developing pedagogical content knowledge. Res Sci Educ 42(6):1027–1047

Chan KKH, Yung BHW (2015) On-site pedagogical content knowledge development. Int J Sci Educ 37(8):1246–1278

Chan KKH, Yung BHW (in press) Developing pedagogical content knowledge for teaching a new topic: more than teaching experience and subject matter knowledge. Res Sci Educ

Clermont C, Borko H, Krajcik J (1994) Comparative study of the pedagogical content knowledge of experienced and novice chemical demonstrators. J Res Sci Teach 31(4):419–441

Davis EA, Petish D, Smithey J (2006) Challenges new science teachers face. Rev Educ Res 76(4):607–651

de Jong O, van Driel JH (2004) Exploring the development of student teachers' PCK of the multiple meanings of chemistry topics. Int J Sci Math Educ 2(4):477–491

de Jong O, van Driel JH, Verloop N (2005) Preservice teachers' pedagogical content knowledge of using particle models in teaching chemistry. J Res Sci Teach 42(8):947–964

Erickson F (1985) Qualitative methods in research on teaching. In: Wittrock MC (ed) Handbook of research on teaching, 3rd edn. MacMillan Press, New York, pp 119–161

Finlayson H, Lock R, Soares A, Tebbutt M (1998) Are we producing teaching technicians or science educators? The consequences of differential demands on trainee science teachers. Educ Rev 50(1):45–54

Geddis AN, Onslow B, Beynon C, Oesch J (1993) Transforming content knowledge: learning to teach about isotopes. Sci Educ 77(6):575–591

Gess-Newsome J (2015) A model of teacher professional knowledge and skill including PCK: results of the thinking from the PCK summit. In: Berry A, Friedrichsen PJ, Loughran J (eds) Re-examining pedagogical content knowledge in science education. Routledge, New York, pp 28–42

Gess-Newsome J, Taylor JA, Carlson J, Gardner AL, Wilson CD, Stuhlsatz MA (in press) Teacher pedagogical content knowledge, practice, and student achievement. Int J Sci Educ

Gotwals AW, Birmingham D (2016) Eliciting, identifying, interpreting, and responding to students' ideas: teacher candidates' growth in formative assessment practices. Res Sci Educ 46(3):365–388

Hashweh MZ (2005) Teacher pedagogical constructions: a reconfiguration of pedagogical content knowledge. Teach Teach Theory Pract 11(3):273–292

Hume A, Berry A (2011) Constructing CoRes—a strategy for building PCK in pre-service science teacher education. Res Sci Educ 41(3):341–355

Lee E, Brown MN, Luft JA, Roehrig GH (2007) Assessing beginning secondary science teachers' PCK: pilot year results. Sch Sci Math 107(2):52–60

Loughran J, Berry A, Mulhall P (2006) Understanding and developing science teachers' pedagogical content knowledge. Sense Publishers, Rotterdam

Magnusson S, Krajcik J, Borko H (1999) Nature, sources, and development of pedagogical content knowledge for science teaching. In: Gess-Newsome J, Lederman NG (eds) Examining pedagogical content knowledge: the construct and its implications for science education. Kluwer Academic, Dordrecht, pp 95–132

Marks R (1990) Pedagogical content knowledge: from a mathematical case to a modified conception. J Teach Educ 41(3):3–11

McDuffie A (2004) Mathematics teaching as a deliberate practice: an investigation of elementary pre-service teachers' reflective thinking during student teaching. J Math Teach Educ 7(1):33–61

McNicholl J, Childs A, Burn K (2013) School subject departments as sites for science teachers learning pedagogical content knowledge. Teach Dev 17(2):155–175

Merriam SB (1998) Qualitative research and case study applications in education, 2nd edn. Jossey-Bass, San Francisco

Nilsson P (2008) Teaching for understanding: the complex nature of pedagogical content knowledge in pre-service education. Int J Sci Educ 30(10):1281–1299

Park S, Chen YC (2012) Mapping out the integration of the components of pedagogical content knowledge (PCK): examples from high school biology classrooms. J Res Sci Teach 49(7):922–941

Park S, Oliver J (2008a) National Board Certification (NBC) as a catalyst for teachers' learning about teaching: the effects of the NBC process on candidate teachers' PCK development. J Res Sci Teach 45(7):812–834

Park S, Oliver J (2008b) Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. Res Sci Educ 38(3):261–284

Rowland T, Huckstep P, Thwaites A (2005) Elementary teachers' mathematics subject knowledge: the knowledge quartet and the case of naomi. J Math Teach Educ 8(3):255–281

Sanders LR, Borko H, Lockard JD (1993) Secondary science teachers' knowledge base when teaching science courses in and out of their area of certification. J Res Sci Teach 30(7):723–736

Schneider RM, Plasman K (2011) Science teacher learning progressions. Rev Educ Res 81(4):530–565

Schön DA (1983) The reflective practitioner: how professionals think in action. Basic Books, New York

Schön DA (1987) Educating the reflective practitioner. Jossey-Bass, San Francisco

Shulman LS (1986) Those who understand: knowledge growth in teaching. Educ Res 15(2):4–14

Shulman LS (1987) Knowledge and teaching: foundations of the new reform. Harv Educ Rev 57(1):1–22

Turner F, Rowland T (2011) The knowledge quartet as an organising framework for developing and deepening teachers' mathematics knowledge. In: Rowland T, Ruthven K (eds) Mathematical knowledge in teaching, vol 50. Springer, Dordrecht, pp 195–212

van Driel JH, Verloop N, de Vos W (1998) Developing science teachers' pedagogical content knowledge. J Res Sci Teach 35(6):673–695

van Driel JH, de Jong O, Verloop N (2002) The development of preservice chemistry teachers' pedagogical content knowledge. Sci Educ 86(4):572–590

van Driel JH, Berry A, Meirink JA (2014) Research on science teacher knowledge. In: Lederman NG, Abell SK (eds) Handbook of research on science education, vol 2. Routledge, New York, pp 848–870