Chapter 22
Commentary on the Expanding Development of Literacy Research in Science Education

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Abstract This commentary situates, summarizes, and critiques the global attempts, as documented in this book, to address the complex language/literacy-science education problem space involving curriculum, integrated learning, classroom practices, challenges, instruction embedded in an inquiry-oriented context, and teacher education and development issues focused on the fundamental sense of science literacy. Few science education policies or curriculum documents recognize a contemporary view of learning science or specify that language is a critical component of science literacy and that instructional attention must be afforded science language, scientific metalanguage, and other fundamental abilities and strategies as part of inquiry-oriented programs. Many countries rely on the language arts or literacy curricula to justify disciplinary literacy in science education. The infusion of literacy goals into science programs requires the reallocation of effort and time, which many educators and teachers will view as impeding the content objectives emphasized in most science curricula, teaching, and assessment. This infusion will necessitate the development of a robust operational definition of science literacy amongst the language/literacy and science education communities that respects the epistemic and ontological nature of science, the development, verification, and implementation of innovative science literacy opportunities in argument-based, multiple information resources and technology-rich science instruction, and new professional learning approaches for language and science teachers in primary, middle, secondary, and postsecondary institutions. Furthermore, the language/literacy and science education research communities may wish to consider secondary analyses of existing research results in order to set the agenda and designs for future research.

Keywords 5-E inquiry cycle · argument-based inquiry · classroom literacy practices · epistemic · communicative and rhetorical functions of language · global perspectives · integrated · interactive and dynamic framework of science

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K.-S. Tang, K. Danielsson (eds.), *Global Developments in Literacy Research for Science Education*, https://doi.org/10.1007/978-3-319-69197-8_22 literacy—derived · fundamental and applied components · just-in-time LLSE instruction and tasks · Just-in-time professional development and ongoing support · LLSE communities/researchers · meta-analyses and metasyntheses · models of learning science and reading/writing · multimodal representations · networks of diverse new and experienced researchers · science and engineering practices · science language (L3) challenges · science literacy pedagogical content knowledge (PCK) · science writing heuristic · the 3-language problem · the three μετά- (metas): metatalk · metacognition and metalanguage · theory-practice gap

22.1 Introduction

This three-part commentary will provide a scan of the language, literacy, and science education (LLSE) landscape; a brief summary and critique of the parts of the book to highlight the results reported and relationships amongst science curriculum reforms, content and language integration, classroom literacy practices, disciplinary literacy and science inquiry, and teacher development; and foci and approaches for future research and development efforts in LLSE. This commentary is from the perspective of an experienced science educator; therefore, it will not capture all the nuances of the authors and may run contrary to perspectives and research preferences in the language and literacy education communities and some in science education. However, it will try to highlight ideas, concerns, and approaches for further considerations and to provoke deliberations.

22.2 Landscape of Language, Literacy, and Science Education

There have been a series of science education reforms since the 1960s that have emphasized various learning theories, goals, and outcomes, teaching approaches, and assessment techniques. These reforms were frequently based on influences, desires, and opinions (e.g., political, international competition, economic development, globalization) that originated outside of education communities, did not consider the pervasive challenges and implementation barriers within the societies, educational systems, and classrooms, and lacked compelling evidence of their achievability and effectiveness. Many of the current international reforms are also lacking informed input from the collective LLSE communities and evidentiary support for the advocated curriculum, teaching, and assessment recommendations. Inquiry-oriented teaching and learning—the goal of most international science education reforms—is still questioned by many classroom teachers, and the evidence for its effectiveness has only gradually been amassed with secondary analyses of research results (Minner, Levy, & Century, 2010). A similar situation has occurred for the current science literacy and the language and literacy in science efforts. Many publications have reported fragmented and isolated research results on the science literacy problem space with very few long-term research agendas that approximated the *gold standard* design of randomized large-scale control and experiment groups. These big agendas require big money and interdisciplinary teams enacting increasingly more rigorous and robust designs as evidence is amassed and the research agenda matures. Such projects are not available to many LLSE researchers. Therefore, these research communities must seek innovative solutions to inadequate funding using novel designs and analysis methods and developing international networks of interdisciplinary researchers focused on this problem space. This book illustrates the potential for developing such global perspectives and networks of diverse new and experienced researchers interested in LLSE.

How people learn science is the essential foundation for curriculum, teaching, and assessment reforms. A brief overview of the related literature reveals various models of learning science and reading/writing, isolated explicit reading and writing instruction independent of science learning experiences, and science textbooks that were encyclopedias of knowledge with readability generally higher than assigned grade use as well as little attention to coordination of print and visual adjuncts (Yore & Tippett, 2014). The pre-1960 *read first, do later* instructional practices reflected the stimulus-response-reinforcement approach of the behaviorist view of learning, where activities, if they occurred, became verifications of what was read, and reading strategies, if provided, were generally bottom-up (i.e., skill and drill) with little attention to top-down (i.e., prior knowledge and literacy of the reader) or interactive-constructive approaches involving concurrent experiences, prior knowledge, and information resources. The 1960s science education reforms were founded on the rejection of reading science textbooks, which was shortened to texts and then generalized to all text and language activities other than listening and speaking in favor of hands-on experiences by many science educators. These inquiry programs did not fully reflect how scientists actually use other information resources and language modes to construct, argue, and communicate their ideas.

Today, contemporary interactive-constructivist views of learning generally assume that learners, young or old, make meaning from concurrent experiences and information and stored knowledge and experiences in working memory within a sociocultural context using public negotiations and private processes. Language—especially written and other learner-generated forms—is an essential resource in learning science; furthermore, language—the placenta for a culture—reflects cultural beliefs, values, and traditions. Therefore, science literacy instruction focused on any population, especially minority and indigenous, needs to consider beliefs and values inherent in their language and their views of knowledge and wisdom about nature and naturally occurring events inherent in their culture.

Science literacy is an old construct, circa 1958, but it does not have a widely shared definition within the LLSE communities. There appear to be three isolated definitions in common use: knowledge about science, reading and writing in science, or participation in the public debate about science-related issues. Some researchers use an integrated, interactive, and dynamic framework of all three views involving a derived component (e.g., knowledge about the science, the nature of science, and scientific enterprise), a fundamental component (e.g., cognitive/metacognitive abilities, scientific dispositions/habits of mind, processes/practices, critical thinking, constructive-interpretative language arts—speaking/listening, writing/reading, representing/interpreting, and scientific metalanguage—enterprise language), and the application of these components in the literate citizens' public debate about science, technology, society, and environment (STSE) or socioscientific issues (SSI). This book and the authors focus mostly on the second view dealing with disciplinary literacy (i.e., fundamental sense) embedded in science learning environments and its manifestations in curriculum, classroom teaching and assessment practices, and teacher education/professional development.

22.3 Summary and Critique of the Contributions

The interesting contributions in this book represent a rekindling of international-interdisciplinary LLSE research and development (R&D) scholarship as many of the current issues are as much about technology and engineering (design/mission-driven innovations) as pure scientific research (curiosity-driven inquiry). Several contributions addressed the theory-practice gap, while others help redefine the problem space with contemporary considerations of second-generation science education reforms and contemporary school and social contexts globally. This book is a start on establishing a global collaborative network of researchers and setting a research agenda in LLSE.

22.3.1 Part 1: Curriculum Issues

Curricula, specific types of education policy, are products of political processes and policymakers (i.e., educators, scholars, public stakeholders, politicians) involved in complex negotiating and lobbying; such policies are influenced by a variety of inputs and persuasion from groups with different degrees of power and influence. Thereafter, educators and teachers spend much time interpreting and enacting curricula without fully understanding how such policies were developed, the sociopolitical factors that influenced their production, and the subsurface intentions. The new USA framework was the product of the National Research Council (NRC, 2012) composed of scientists, university faculty members, and members of society. Elizabeth Moje, P. David Pearson, and I were invited to address an NRC Steering Committee hearing. We lobbied for a clearer definition of science literacy that was composed of dynamic, interacting, fundamental, derived, and applied components that would embrace the communicative, epistemic, and rhetorical functions of language in doing and learning science. Unfortunately, our effort had less than the desired impact on the new framework. Although science literacy is not explicitly mentioned, some features advocated can be implied in the science and engineering practices: "#2—Developing and using models [representations], …

#7—Engaging in argument from evidence [rhetorical function], … #8—Obtaining, evaluating, and communicating information [communicative function]" (NRC, 2012, p. 42).

Several other international science curricula have evolved foundational assumptions, expanded their goals, and recognized instructional approaches over the earlier views of learning and limitations of science teaching as solely inquiry-oriented. The USA's framework has assumed learning and teaching involves interactive-constructivist views, science is as much about argumentation as inquiry and engineering is about design not applied science, and broadens the goals—core ideas, science and engineering practices, and crosscutting concepts (NRC, 2012). The core ideas listed are idiosyncratic to the composition of the curriculum committee and development process and would likely vary if these factors were changed slightly. The interdisciplinary crosscutting concepts and the science and engineering practices provide a potential context for anchoring and justifying the fundamental and applied components of science literacy; that is, the cognitive, social, and physical activities that scientists and engineers do to investigate, evaluate (argue, critique, analyze), and develop explanations, solutions, and innovations. The specificity of the science and engineering practices and crosscutting concepts can be debated, but they are meant to stress the commonalities across the life, earth-space, physical, and engineering sciences and provide foundation for developing interdisciplinary programs like science, technology, engineering, and mathematics (STEM). Unfortunately, the science and engineering practices do not fully reflect the epistemic, communicative, and rhetorical functions of language in making, arguing, and reporting meaning and understanding. This limited view of language and literacy in science curricula requires advocates, as illustrated by several authors in this book, to rely on their prescribed language arts curricula to justify a fuller range of language and literacy strategies and to persuade teachers of science about their inclusion.

The curricula in Australia, Norway, and Singapore, which were influenced by the recognition of the ever-increasing diversity in schools and the value of disciplinary literacy, are similar to the emphases in other parts of the world. They recognize the importance of science literacy and how it differs from traditional definitions of literacy and the belief that science literacy is connected to improved achievement. A hierarchical framework for disciplinary literacy abilities (Shanahan & Shanahan, 2008) that progresses from the basic level (applicable to most disciplines) to intermediate (applicable to some disciplines) and advanced levels (applicable to specific disciplines) underpins these studies.

Knain and Ødegaard reported on the Budding Researchers project evolving from the general curriculum reform across the disciplines that infused literacy and opportunistic instruction (as needed) within science inquiries and projects. Norwegian classroom and lead teachers collaborated to develop and evaluate embedded writing, reading, and speaking in their science teaching that considered science processes, basic literacy skills, and scientific metalanguage. The authors believed that permanency of printed language and representations allow the reflections necessary to analyze data and to generate and check evidence-based claims, theory-based explanations, and cause-effect mechanisms. Davison and Ollerhead reported similar results in Australia where science teachers implemented English as a second language and addressed concerns about declining achievement of low-SES students. These students' underdeveloped language ability limited both their participation in inquiry-based settings and group discussions and their understanding of evidence-based reasoning and argumentation. The teachers believed that the overcrowded curriculum and their inability to develop and infuse authentic science literacy opportunities and practices in their classroom teaching were barriers to implementing literacy-rich SSI and problem-based learning. Ho, Rappa, and Tang reported on professional learning programs involving design-based research (lesson studies) situated in Singapore's attempt to implement the Whole School Approach to Effective Communication in English mandate. The science teachers benefited from just-in-time professional development and ongoing support from school, university, and ministry of education resource people. One exciting design study involving four teachers who planned and enacted science lessons using a premise—reasoning—outcome approach focused on teaching students how to construct scientific explanation (see Tang, 2016, for ontological attributes of scientific explanations).

These three chapters revealed the lack of a clear, concise, and shared definition of science literacy and confirmed the reluctance and limited awareness of teachers of science, especially science specialists, to provide embedded language and literacy support or explicit instruction within the context of science inquiry and projects by diverting instructional time and effort away from traditional content outcomes. The struggle to convince teachers of science would be much easier if the authorized science curricula specifically identified fundamental literacy and application components and the parts, abilities, and strategies in these components as prescribed learning outcomes.

The research designs used reflect the current R&D into the policy, curriculum implementation, and professional learning problem space—but they have limited generalization and strength of claims. LLSE researchers would be well served by ensuring that future case, participatory action, and lesson design studies have common data sources and interpretative frameworks to allow for meta-analyses (quantitative results) and meta-syntheses (qualitative results) from and across a number of small-scale studies. Furthermore, these contributions illustrate the need for policy and curriculum research to inform LLSE researchers about how they could more fully and effectively participate in these endeavors and become influential change agents in promoting science literacy in science curricula.

22.3.2 Part 2: Content and Language Integrated Learning

All students are science or other disciplinary language learners (L3); language conventions and traditions are essential parts of a discipline. The ever-increasing diversity in classrooms worldwide has highlighted globalization, political unrest, and dislocation of peoples and the related needs of students in schools where their home language/native tongue (L1) does not align with the language of instruction (L2) or the target disciplinary language (L3). Visits to schools in Vancouver, Minneapolis, Stockholm, Berlin, Melbourne, London, Capetown, and other urban areas will document students speaking numerous nondominant/official languages. Many multilingualism and multiculturalism students frequently demonstrate lower achievement than dominant-language-speaking students.

Clearly, these multilingual sociocultural contexts complicate the three-language problem, which only involves variations of nonstandard and standard forms of a single language. However, the diversity represents richness of values, beliefs, and experiences rather than a deficit in the construction of understanding. The difficulty is not the richness of resources but rather how to access, engage, and coordinate these memories and concurrent experiences on the cognitive workbench. The following contributions report on some content and language integration efforts that addressed science literacy in diverse settings.

Markic reported on participatory action research involving science and German-as-a-second-language teachers planning and developing materials. She found success in helping linguistically disadvantaged Grades 5–8 Turkish- and Arabic-speaking students in science lessons using small group (2–3 students) and individual methods that included intercultural understandings to engage the diverse resources that these students bring to the learning environment. The science teachers asserted that the second-language students needed less support in understanding and writing when using these materials, while the students reported they were more motivated and willing to share their writing products. Lo, Lin, and Cheung used lesson studies in Hong Kong to document the rationale and collaborative approach of science teachers, English language teachers, and university faculty to provide scaffolding and help reasonably proficient English-as-a-foreign language students (age 13–15). They developed, used, and evaluated integrated genre-based content and language lessons focused on writing sequential explanatory texts (e.g., science talk, terminology, representations, words, and phrases) that described and explained the target phenomena to bridge the three languages. Their results suggested that the materials and scaffolding enhanced students' science literacy. Msimanga and Erduran explored South Africa's diverse multilingual classrooms where the language and science problem is compounded by the facts that students learn English as their third or fourth language and their teachers are not proficient in English. However, it was informally reported elsewhere that many parents support the use of English during instruction as they see it as necessary for future work or education. Lesson transcripts illustrate how the participating teachers' metatalk focused on the conceptual content as a discursive tool but did not address the language of science and its demands and functions. Wu, Mensah, and Tang conducted case studies in New York and Singapore secondary schools focused on English language learners (ELL). These ELL populations have different socioeconomic and sociocultural backgrounds and motives; that is, immigrants from the Dominican Republic seeking to complete high school certificates and students in a private school seeking entrance to English-speaking universities. The New York case study revealed that L1 can be used for learning scientific content but is seen by some students as a hindrance to their acquisition of English. The Singapore study of teacher-directed dissemination of knowledge and procedures provided few opportunities for student–teacher or student–student interactions, but the students did use their L1 in laboratory and small-group settings. Analysis revealed that comfort with using the English language was a significant predictor of students' science achievement.

These small-scale studies focused on content and language integration where students are learning a majority language and language of instruction (L2) at the same time as they learn the language of science (L3). Such studies are needed to better understand the complexity and competing factors involved in learning and teaching environments with students of diverse linguistic and cultural backgrounds. Applying an interactive-constructive view of learning and teaching suggests the problem is not lack of cognitive resources required to construct meaningful understandings, but rather that they are stored in students' L1, which differs from the desired dominant language and the access and retrieval of these stored resources from long-term memory may require the use of students' home language.

Pragmatics as well as theoretical considerations need to be addressed regarding the theory-practice gap in literacy-science teaching focused on science literacy. English is often referred to as the lingua franca for international science, but findings from an English language context may not be fully applicable to other language and science literacy spaces (e.g., Mandarin, Swedish). Integration of language and literacy into science learning and teaching is a very challenging task for specialist teachers who lack insights into the complexities of the language system or the nature of science. Science literacy has received increased attention in recent years, but language and literacy educators appear to concentrate on the *fundamental* component while science educators appear to concentrate on the *derived* component. Furthermore, LLSE researchers do not always address the functions of language completely with many concentrating on communications and less so on meaning making (epistemic function) and argumentation (rhetorical function).

Fundamental science literacy instruction, the focus of this book, needs to be opportunistic by capitalizing on authentic science learning environments that require just-in-time instruction and tasks. The contextual fabric of the inquiry will avoid the so-called transfer problems encountered by much of the language instruction outside of science classrooms. Opportunistic literacy instruction requires convinced, confident, and proficient science teachers or teacher teams that can grasp available opportunities and provide metatalk (i.e., talking about the discourse being used or targeted rather than simply talking about the concepts being explored) about the language or literacy strategies. Integrated LLSE instruction needs to recognize that students are not deficient in background, but rather they bring a rich array of resources for making sense of the natural world—These ideas may be encoded and stored in long-term memory using native languages that are different from the language of instruction. Few teachers will be proficient in these native languages; therefore, instructional strategies will need to be developed to use the collective language abilities of the class and low-demand visual tasks (e.g., student drawings or other representations) to help individual students access, engage, and use these cognitive resources in their meaning making.

22.3.3 Part 3: Classroom Literacy Practices

Classroom literacy instruction can involve a variety of tasks, activities, and interventions focused on enhancing students' communicative, epistemic, and rhetorical strategies. Strategies are assumed to be clusters of commensurate operations, moves, and skills that can be substituted for one another within the cluster and used to accomplish the same function or outcome. Unlike skill development based on rote memorization and drill and practice, effective strategies instruction should involve mindful choice between alternatives or informed selection amongst options. An example of this perspective applied to science literacy, such as data interpretation to reveal empirical relationships (evidence-based claims), might involve critical thinking about, data manipulation, and representations of observations, data tables, numerical calculations, diagrams, graphs, flow charts, other data displays. Each of these options could partially illustrate potential patterns between the dependent and independent variables. The decision to use one, or a combination, of these options will depend on other factors—audience, type of data, presentation media, available technologies, and resources, etc. The following contributions illustrate literacy instruction and methodologies in various countries, sciences, and classroom settings.

Wilson and Jesson used case studies of New Zealand science teachers (2 each in Grades 7, 9, and 11) to document the enactment of the national curriculum on subject-specific literacy. Interpretations of classroom observations, teacher interviews, and measures of subject literacy pedagogical content knowledge (PCK) used to document the teachers' beliefs, knowledge, and practices indicated that the teachers were using traditional teacher-directed approaches with supplemental vocabulary definitions. The authors believed that there was a need to expand the learning and assessment beyond content outcomes to include reading, writing, and critical literacy. Cavalcanti Neto, Amaral, and Mortimer investigated the role of discursive interactions in three multilingual Brazilian Grades 6 and 7 classrooms. Results revealed differences in the teachers' use of language and literacy: one used an initiate-response-evaluate method, one used an interactive-dialogic to access and partially use students' ideas, and one used an interactive-dialogic method to engage environmental issues. The authors believed that science literacy is often limited to an authoritative reading and writing of scientific texts and could be made more dialogic by including student-generated language, texts, and representations, discussion, and argumentation. Jakobson, Danielsson, Axelsson, and Uddling investigated Swedish multilingual Grade 5 students' interactions and meaning making. Results revealed that the teacher and students engaged in meaning-making activities involving a variety of semiotic resources (e.g., representations, speech, gestures, writing) to develop science literacy. However, some classroom practices (e.g., stress of exactness, meticulousness, writing forms) appeared to hinder meaning making. He and Forey examined a Grade 9 science classroom's meaning making with various resources and their affordances (e.g., language, gestures, animation) as part of an Australian professional development project. Analysis of a video recording revealed that gestures and animation provided temporal and spatial meaning while language mediated knowledge and established conceptual links and organization.

These four interesting contributions generally lacked a shared working definition of science literacy; and the participating teachers focused on content knowledge with little consideration of learning the epistemic and rhetorical functions of language and the ontological requirements of science. However, these chapters provided foundations for defining and specifying contextual language in science demands/actions. The listing of teacher actions and strategies, the multimodal resources involved in meaning making, and the measurement of science literacy PCK were important contributions that could be useful to LLSE researchers.

Explicit instruction about strategies (i.e., clusters of commensurate operations, moves, and skills) should involve the three μετά- (metas): metatalk, metacognition, and metalanguage. Metatalk involves talking about the target concept, which is reasonably common in conceptual change teaching where learners need to be convinced to give up or modify their existing conception for a more compelling, robust alternative concept and to link the new concept to established ideas and practices. However, literacy instruction also needs to involve metatalk about the literacy strategies that considers the metacognitive awareness (declarative knowledge—what, procedural knowledge—how, and conditional knowledge—why and when) and metacognitive self-management or executive control (planning, monitoring, and regulating) of the specific strategy and other strategies in the commensurate cluster. Furthermore, literacy instruction needs to consider scientific metalanguage (enterprise terms) associated with the nature of science (evidence supports not proves as in mathematics, relationships amongst theory, model, hypothesis, prediction, inference, and observation, etc.).

22.3.4 Part 4: Disciplinary Literacy Challenges

Science language (L3) incorporates terms from everyday, academic, and other discipline-specific languages and enterprise terminologies and unique symbolic, visual, genre (form/function), and style features that makes it challenging for many producers and users of scientific oral and print texts. It is not uncommon that highly proficient academic English students find the move into comprehending and producing scientific English language and text problematic and variable across different science disciplines with their dense terminology and heavy reliance on symbolic representations and mathematical features. These problems are multiplied for ELL or other official language learners with nonstandard home and minority everyday native languages. Students without some prior informal or formal understanding of the target ideas and experiences with the oral or print science text are expected to face challenges of lack of prior conceptual and experiential resources. The following studies explored some of these challenges for proficient and nonproficient dominant language speakers as they navigate amongst their home, instruction, and scientific languages and texts.

Liu examined the language and symbols in introductory secondary school chemistry textbooks used in Singapore. The functional analysis of selected textbooks illustrated that chemical formulas and equations involve several numerical and symbolic conventions to denote chemical structures/compositions and the mechanics of reactants and products in chemical reactions. These well-established conventions challenge many novice and nonexpert readers of chemistry. Danielsson, Löfgren, and Pettersson examined the use of metaphors in a Swedish and two Finnish-Swedish secondary chemistry classrooms. Analysis of video recordings of classroom interactions indicated that the teachers used a variety of scientific, everyday, and anthropomorphic metaphors as foundations for the properties of the atom. However, the native language (Swedish rather than English) made a difference in whether a concept label might be metaphorical in nature. Ge, Unsworth, Wang, and Chang explored the design of visual adjuncts on reading comprehension and understanding of print-visual texts in Taiwan. This clever two-group quasi-experimental study examined the effects of image design on reading comprehension and meaning making involving visual and verbal text using a five-phase interview (i.e., image only, addition of caption, addition of text, text with synonymous image, selection, rationale of most appropriate image) to partition the reading comprehension of 12 Grade 7 students in different textual conditions; a comparison group read the text with textbook images, and a treatment group read the same texts but with a tree-structure image. Results suggested that the textbook image did not activate as many themes as the tree-structure representation, but surprisingly the influence of prior knowledge was negligible.

The results from this part illustrate the need to consider language's sociocultural context, the visual and print resources involved, and linguistic features to be considered. Much LLSE research has been done in English-language settings. However, one needs to be cautious about generalizing these results to other languages and settings because of linguistic differences. These studies reveal that sociocultural beliefs/values, traditions, and conventions are embedded in the language. The systemic functional linguistics and social semiotics interpretative frameworks used in these contributions provide a sound basis for considering other sciences and topics as well as language modes or resources (Liu's explanation of semiotics appears to be useful in physics as well as chemistry topics).

22.3.5 Part 5: Disciplinary Literacy and Science Inquiry

The collaboration and integration of the language and literacy community (disciplinary literacy) and the science education community (science as inquiry, engineering as design, evidence-based argument, and science and engineering practices) is the central focus of the next three studies. These lesson studies implicitly assumed that literacy in the science classroom should reflect what scientists do, support students in learning the concepts and practices of science, and enhance their application to the public debate about STSE or SSI problems leading to sustainable evidence-based solutions. These assumptions closely approximate a contemporary definition of science literacy composed of fundamental, derived, and applied components; they appear to use a constructive-interpretive view of the language arts (speaking-listening, writing-reading, representing-interpreting) where students generate oral, print, and visual texts as epistemic, rhetorical, and communicative tools in learning about, persuading others, and applying science.

Ødegaard explored how six elementary teachers implemented the Budding Scientist program as part of the Norwegian emphasis on disciplinary literacy. This program embedded students' use of multiple sources of evidence (primary hands-on experiences and secondary experiences: text-based inquiries, external information sources, representational tasks, etc.) to construct understanding in argument-based inquiry. Analysis of classroom video recordings, observations, and interviews revealed multiple learning modalities (read-it, write-it, do-it, talk-it adapted from the *Seeds of Science/Roots of Reading* program) distributed across different phases of inquiry (preparation, data, discussion, communication). The teachers' greatest challenge was to find the time and courage for consolidating conceptual learning in the discussion and communication phases. Students expressed concerns that literacy and the role of text in science were not clear. Tang and Putra explored the implementation of Singapore's subject-specific literacy mandate using design studies where four secondary school chemistry and physics teachers developed, enacted, and tested integrated literacy and science lessons. The instruction-infused literacy strategies were designed to support students in constructing scientific explanations using the 5E Inquiry Cycle (engage, explore, explain, elaborate, evaluate). Interpretation of classroom activities and interactions illustrated the literacy activities and support of scientific practices and suggested specific ways of reading science, translating information amongst or between various formats, and writing and evaluating explanations. Tytler, Prain, and Hubber explored students' construction and use of multimodal representations in Australia. They engaged urban junior secondary school teachers and students in collaborative lesson studies about the rock cycle. Analyses of lesson plans, classroom videos, instructional artefacts, and teacher–student interactions revealed partially how to address the theory-practice gap and challenges within authentic/meaningful science inquiry. The locus of control during the professional learning project was transferred to teachers as they gained self-confidence and took increasing leadership in planning and enacting the guided-inquiry approach (student-generated representation, experimental or alternative sources of evidence, discussion and evaluation of representation, assessment of learning).

These contributions implicitly endorse an interactive, dynamic relationship amongst the three senses (fundamental, derived, and applied) of science literacy; their design and results demonstrate how enhancement of fundamental literacy strategies helped improve content understandings and promote participation in the public debate about science-related issues. The opportunistic infusion of science literacy strategies into authentic inquiry learning and use of multiple information sources place increased demands on teachers and an expanded need for science literacy PCK not available to many preservice and practicing science teachers from their previous professional education. The studies started to outline the demands as well as the planning and classroom practices needed to address integrated science literacy and science learning. Participating teachers developed their science literacy PCK *in situ* as they planned, enacted, and evaluated science lessons on a variety of topics and grade levels with multiple resources and language modes using the collaborative support and mentoring of peers and experts. Each instructional approach avoided transfer problems by infusing the literacy strategies into actual science learning environments. These studies may lack generalizability, but they indicate the need for teacher education and professional development involving ongoing support, mentoring, and cascading leadership that is not common in many programs. Furthermore, they indicate the need for science curricula to explicitly identify fundamental and applied components of science literacy along with the commonly identified derived understanding component. Without this endorsement in the authorized science curricula, it is much more difficult to convince science teachers of their fundamental and applied science literacy responsibilities.

22.3.6 Part 6: Teacher Development

This part naturally flows from earlier parts of this book by exploring issues and tensions faced in preparing science teachers to integrate disciplinary literacy into their teaching and the ongoing difficulty in teacher education related to changing the effects of teachers' previous experiences in school and university science classes. Many university students selecting science education as a teaching area have been successful in their prior science courses, which were frequently taught with teacher- or professor-directed lectures, verificational laboratory work, and knowledge-focused assessments. Students see little need to change such personally effective methods (the *It's not broke; why fix it?* perspective); therefore, they adopt these well-engrained instructional methods. Language in these approaches assumes a communication function used to disseminate knowledge, evaluate understanding, and manage behavior. Contemporary language- and literacy-oriented science instruction is different because it assumes epistemic and rhetorical functions for language as well as the communicative function. The three contributions outline efforts to expose, convince, and empower preservice and practicing teachers and university lecturers of these functions and related tasks and strategies.

Espinet, Valdés-Sanchez, and Hernández illustrated how the three-language problem can become more complicated in places like Catalonia, Spain, where there are at least three common public languages as part of belonging to the European Union and regional aspirations for nation status. This context makes learning the language of science even more complex than in many countries and likely places it at a lower priority than where English is spoken at home and is the basis for learning scientific English in school. They examined 39 primary school preservice teachers' beliefs and expectations about the Content and Language Integrated Learning approach. Analysis of the participants' science and language narratives revealed that their science experiences were more related to negative school contexts, whereas their language experiences were connected to a variety of positive out-of-school contexts. The implications for teacher education are related to how to connect these formal and informal experiences and to establish the value and utility of language, science, and science education. Hand, Park, and Suh tracked changes in 28 middle school teachers' epistemic orientations and pedagogical practices as they experienced and implemented the Science Writing Heuristic (SWH) approach during a three-year immersion argument-based inquiry professional development project in the USA. Analysis of teachers' epistemic orientation and students' critical thinking revealed that teachers started to view science as argument and language as an epistemic tool and that improved implementation of the SWH approach led to enhanced critical thinking by the students. The authors suggested that professional development is not a quick fix, teachers need to be aware that language is essential for learning of science, and science cannot be done without language, especially written language. Airey and Larsson explored the disciplinary literacy goals related to university, workplace, and society of 30 undergraduate physics lecturers in Sweden and South Africa. These differences pose significant challenges for preservice physics teachers who have to navigate across the disciplines of physics (hierarchy structure) and education (horizontal structure). Analysis of semi-structured interviews revealed the lecturers had similar disciplinary literacy goals for their students and very different ideas about their responsibility to teach literacy and the use of the semiotic resources. Results indicated that the lecturers moved toward a broadened view of science literacy that includes using cognitive resources and various information sources in different contexts, but was still limited to the communicative function, neglecting the rhetoric and epistemic functions.

The professional education and learning of science teachers to incorporate science literacy into their beliefs and values, instructional goals, and PCK cannot be achieved by lecture or increased time in traditional coursework. It requires coordinated efforts across university departments and the teaching profession with authentic learning experiences involving planning, classroom engagement, and reflection-on/reflection-in action. Contemporary views of science literacy are a major departure from the traditional expectations and experiences of preservice and practicing teachers of science. Many science teacher education programs involve several departments in the science faculty and the general education, language and literacy, and science education departments of the education faculty—these two faculties' views about science literacy are frequently not aligned. Many science courses stress and reward content mastery, while general, language/literacy, and science education courses do not provide consistent views about goals, teaching, and assessment across the integrated components of science literacy for citizenship. Therefore, many teachers leave their initial education with rather poorly organized and justified traditional beliefs, values, and practices about effective science teaching and assessment. This claim can be verified by visits to early-career and experienced science teachers' classrooms where teacher-directed lectures are the most common teaching approach to be found. Professional development takes time. A long-term conceptual change approach to teacher education and professional learning with ongoing clinical experiences and mentoring is needed to achieve the goal of teachers facilitating student-directed learning with a variety of experiences and resources.

22.4 Closing Remarks

It has been both pleasant and educational reading—consolidating my reactions and commenting on this book that gives a global perspective and overview to the complexity of the language/literacy and science problems space and that considered curriculum, content and language integration, classroom practices, disciplinary literacy within science inquiry, and professional learning components. My closing remarks recognize the pragmatics of an edited book endeavoring to achieve these worthwhile goals and different preferences about research design within and across the LLSE research communities. These remarks are not intended to be viewed as negative or to reignite the *paradigm wars*. Rather, they are provided to reinforce a few ideas and to move the concerned communities toward shared deliberations, insights, and consensus about their commonalities and differences, and relationships amongst science literacy, science understanding, and participatory citizenship. These collaborative efforts should provide a basis on which to (a) develop more useful operational definitions, compelling arguments, and empirical claims, (b) explicitly recognize the limitations of hastily drawn global assertions/claims and recommendations, and (c) outline potential actions and research addressing integrated language, literacy and science curricula, learning, teaching, and assessment.

22.4.1 Science Literacy

A consensus operational definition of science literacy is lacking in LLSE literature. Science literacy was originally defined as knowledgeable in science (derived sense) and later revised to include a language component (fundamental sense) and recently evolved to include an application component (citizen participation sense). The derived sense, which reflects authorized curricula, can include knowledge about the nature of science, big ideas such as core ideas and crosscutting concepts, and science, technology, and social interactions. The fundamental sense can include cognitive/metacognitive abilities, emotional dispositions/habits of mind, attitudes, science and engineering practices/processes, critical thinking, and scientific language (speaking-listening, writing-reading, representing-interpreting, enterprise terms). The application sense can involve the fundamental and derived senses required of an informed, active citizen in the consideration of public science, technology, and environment-related issues to make informed decisions and produce sustainable solutions.

The definition of science literacy continues to evolve toward the interacting perspective, as no component should or can standalone. The NRC (2016) report has provided an expanded view of science literacy that goes beyond the individual to include the community/society; it "identified four additional aspects of science literacy that, while less common, provide some insight into how the term has been used: foundational literacy, epistemic knowledge, identifying and judging scientific expertise, and dispositions and habits of mind" (p. 5). Science literacy and its subsumed components should consider the criticality needed in our rich, diverse, and un-reviewed information communication technology age that can be elaborated and repositioned to address an elite version focused on STEM careers and expertise by increasing the specificity and proficiency levels.

The expressed intention of this book was to focus on the fundamental sense (disciplinary literacy), but just about every contribution considered the fundamental sense in conjunction with the derived or applied senses. However, several authors do not consistently recognize the functions of language in doing and learning science—communication, construction, and argumentation of/about knowledge—nor the nature of science involving unique epistemic features and ontological requirements.

22.4.2 Explicit Views of Science Learning

Researchers and research reports about science literacy need to specify their assumed view of learning, which will influence beliefs, values, and practices about teaching for science literacy and the interpretation of data and results. Taking a behavioral view would lead to assumptions that science literacy is a collection of language skills applied to science that could be achieved by a drill-and-practice approach. Taking an interactive-constructive view involves learners making meaning from a combination of prior knowledge, experiences, and beliefs and concurrent sensory experiences and information sources within a sociocultural context and defined content area with public and private negotiations (see Hand et al., in this book). The interactive-constructivist view moves science literacy instruction toward strategic clusters and interacting abilities, the three μετά (metatalk, metacognition, metalanguage), and group and individual negotiations using multiple modes of language in constructing and representing understanding.

22.4.3 Science Education Policy and Curricula

Policy and curriculum development do not always consider the realities of schools, classrooms, students, and teachers fully. Sometimes the most powerful members of a development group can unknowingly move the policy and curriculum toward unachievable ends. The 1960s process versus product dilemma and inquiry-oriented teaching are illustrations of such ends brought about by well-meaning scientists and philosophers.

The current science reforms and curricula continue to emphasize science as inquiry but have added engineering as design, science and engineering practices, and implicitly recognized the importance and some functions of language (communications and argumentation) as epistemic tools in doing and learning science. However, they stress approaches without fully considering the problematic features and challenges for teachers. Many generalist and specialist teachers with limited science knowledge, PCK, and experience working in challenging linguistically diverse environments are unable to successfully implement the outcomes and teaching methods. The barriers—lack of background, support, equipment, resources, preparation, and instructional time; large class sizes; overcrowded curricula—overwhelm these teachers.

22.4.4 Theory-Practice Gap in Science Literacy

Collectively, the chapters in this book have provided partial evidence for several literacy strategies and identify the need to address the complex and potential interactions amongst educational policy, curriculum, science literacy instruction, and teacher education and profession development within argument-based inquiry environments. This is important as analysis of teacher magazine articles on classroom practice involving language and literacy activities embedded or associated with the science education program revealed that most of the recommended practices, regardless of their efficacy, do not have sufficient research foundation and, therefore, do not qualify as evidence-based practices (Jagger & Yore, 2012).

22.4.5 Teacher Education and Professional Learning

Teacher education and professional learning must address the difficulty of changing teachers' established beliefs and practices—many of which go back to their experiences as an elementary, middle, or secondary school student or their post-secondary science courses. Clearly, initial teacher education and continuing professional development cannot be viewed as quick fixes. One contribution in this book used a PCK measure for science literacy that holds promise for further efforts. Furthermore, policy scholars need to explore the internal politics within curriculum development and teacher education programs to determine the factors influencing program, recruitment, and enrolment management efforts. Based on my experience, science and disciplinary literacy educators hold minority positions with little power to influence these decisions.

22.4.6 Building More Compelling Research Claims

This edited collection has illustrated the potential influences and differences among native/home languages, cultures, societal and environmental contexts on the use and interpretation of language in doing and learning science. Any generalization to other non-English languages, schools, and societies based on English language settings and results must be questioned based on the different linguistic structures of these languages and the classroom settings, cultural values, and beliefs associated with Anglo communities. The results of some chapters have demonstrated how sociocultural and linguistic contexts change the classification and interpretation of data—verb-based compared to object-based iconic languages like Mandarin, nucleus as metaphor in Swedish, etc.

More literacy-science research using all types of designs is needed, but it may be time to encourage convergence of existing results before striking out on divergent R&D agendas. How can we naturally integrate language, literacy, and science into argument-based inquiry, design, and science and engineering practices? Case, participatory action, lesson, and design studies and quasi-experimental studies have been useful in surveying the problem space, defining driving questions, and illustrating unique and potentially powerful teaching/learning approaches, data collection, and data analysis techniques. But the need for (a) inclusive definitions of science literacy, (b) understanding the distinctive nature of science, and (c) models of science learning that respects the ontological requirements, epistemic practices, and metalanguage of science overrides doing more of what has been done without these definitions.

The integrated language, literacy, psychology, measurement, and science communities must form multidisciplinary, cognitive science, and multi-methodological research networks to achieve fiscal efficiencies and address the more complex issues in the language-science learning, teaching, and assessment problem space because of the multiple information sources and communication technologies available. The international nature of the author teams and research environments in this book illustrates the potential influence of home/native language on the demands and requirements of doing and learning science in different cultural, social, and environmental contexts. A first step would be to conduct meta-syntheses and meta-analyses of existing interpretative and quantitative results to establish a firmer foundation and landscape of the language-science problem space and compelling evidence-based practices (Rossman & Yore, 2009). The history (1999–) of the SWH approach based on the authors' opinions, numerous related qualitative and quantitative studies, and the meta-analysis and meta-synthesis of these results illustrated how the theory-practice gap was addressed and how an evidence-based science literacy practice was established (Jagger & Yore, 2012). Finally, there are multiple needs for policy research and action—participatory action research that clarifies the basis for curriculum decisions and teacher education program revisions involving science literacy education.

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