J Sci Teacher Educ (2012) 23:559–577
DOI 10.1007/s10972-012-9271-6

Mind the Gap: Looking for Evidence-Based Practice of *Science Literacy for All* in Science Teaching Journals

Susan L. Jagger · Larry D. Yore

Published online: 11 March 2012

Abstract *Science literacy for all* is the central goal of science education reforms, and there is a growing importance of the language arts in science. Furthermore, there are strong calls for teacher professionalism and self-directed professional learning that involve evidence-based best practices. This raises questions about whether science teaching journals' recommendations are anchored to high-quality evidence. We found that (a) most National Science Teacher Association journals' science literacy recommendations have weak or no evidence base and (b) those with evidence reference teaching journals, teacher resource books, and literacy education more often than science education research. We concluded that all participants in the knowledge production cycle and transfer process—authors, editors, and reviewers—need to encourage evidence-based practices anchored to ongoing reforms and to literacy and science education research.

Keywords Science literacy · Language in science · Evidence-based practice · Professional learning

Introduction

This article addresses two central issues: (a) professionalism and professional learning in science teaching informed by evidence-based best practice and (b) the National Science Teachers Association (NSTA) journals' promotion of literacy opportunities, activities, and strategies embedded in science instruction as well as

S. L. Jagger (✉)
Ontario Institute for Studies in Education, University of Toronto, Toronto, ON, Canada
e-mail: s.jagger@utoronto.ca

L. D. Yore
Department of Curriculum and Instruction, University of Victoria, Victoria, BC, Canada
e-mail: lyore@uvic.ca

the evidentiary foundation for these recommended practices. The context of this problem space is problematized by the lack of a shared definition of *science literacy for all*, acceptance of the call for evidence-based practice (EBP), and clarification of evidence required to justify professional practice. Most calls for EBP give preference to quantitative results from experimental studies or random controlled trials as the "Gold Standard". However, such a stance unfortunately does not recognize cumulative evidence from various scholarly sources, qualitative and mixed-methods research traditions, and theory-based applications as justification for instructional practices. Since current science teaching articles are frequently used as instructional resources in teacher education programs and as implementation foci in group and self-directed professional development activities, this study was intended to inform authors, editors, reviewers, researchers, teacher educators, and teachers of the status and implications of evidence-based teaching articles regarding science literacy and literacy strategies and activities in science.

Background

Professionalism commonly refers to a body of practice regulated by a defined community, authority, or judicial panel in terms of entrance, acceptable practices, ethical conduct, and discipline. Teaching practices are not controlled as much as accounting, engineering, legal, medical, or other recognized professions. Colleges of teachers or licensure requirements for teacher education programs, initial entry, and continued certification govern teaching in Canada and the USA. Some jurisdictions require continuing education for recertification, commonly called professional learning or professional development, to maintain professional status. Universities, professional associations, and school districts can formally offer these experiences as credit courses or noncredit activities. However, there is a growing realization that many teachers want personalized approaches that value self-directed professional learning and EBPs in science literacy instruction.

Professional Learning

The US National Board for Professional Teaching Standards (NBPTS) certificate is a post-entry program designed to improve high-quality professionalism, classroom practice, and school leadership. Standards are identified in 25 areas for specific developmental levels (for a complete list, see http://www.nbpts.org). This certification process requires individual teachers to enact a self-directed program of study working with a certified mentor to complete tasks, conduct action research, and achieve the established standards. Central requirements are evaluation, reflection, regulation, and justification of curricular, instructional, and assessment decisions about preparing for and establishing favorable contexts, advancing, and supporting student learning by professional teachers. This places prime importance on rational, evidence-based decisions about what to teach, how to teach, and what data justify teaching and learning effectiveness.

Evidence-Based Practice

The Commission on Behavioral and Social Sciences and Education (US National Research Council [NRC] 2000) reported that some curricula and teaching are anchored in outdated principles, traditions, and learning theories. Numerous instructional ideas and practices are included in science education with various degrees of theoretical justification and empirical evidence. Millar and Osborne (2009) considered practices that might have sufficient evidential basis; they suggested that *wait time* (Rowe 1974), *formative assessment* (Black and Wiliam 1998), and *cognitive acceleration* (Adey and Shayer 1990) had enough research support for such acceptance and teacher uptake. Interestingly, they did not identify learning styles and inquiry teaching as EBPs. These, and other instructional practices, appear to be popularized by promotional efforts, but not empirical research findings. Those practices that fall within the boundaries of EBP are guided by rigorous, valid, and scientifically based research and can improve the effectiveness of teaching and learning. Such practices include reduced class sizes for grades K to 3, life skills training for junior high school students, and phonemic awareness and phonics instruction for early readers (IES 2003).

The EBP model requires that practitioners (here, teachers of science) familiarize themselves with the research on curricular and instructional practices, that this research addresses teachers as the target audience and end users, and that professional codes and recommendations are based on quality research results in sufficient quantity and consistency to define best practices (Hayward and Phillips 2009). The US Institute for Educational Sciences (IES; Shelley 2009) provided standards for quality of evidence considered to be either strong, possible, or weak evidence for specific instructional programs, resources, and practices based on research design, rigorous methods, valid and reliable measurements, comprehensive data sources, appropriate data analysis, and compelling arguments involving legitimate claims, strong theoretical backings, and sound warrants of the data as evidence for or against specific claims or counterclaims. Shelley (2009) identified four agencies in North America that synthesized evidence sources to identified best practices and made these results available to a wide audience:

- Best Evidence Encyclopedia (http://www.bestevidence.org)
- Campbell Collaboration (http://www.campbellcollaboration.org)
- Comprehensive School Reform Quality Center (http://www.csrq.org)
- What Works Clearinghouse (http://ies.ed.gov/ncee/wwc/)

None of these agencies currently focus specifically on *science* literacy, learning, teaching, assessment, and instructional programs and resources. Therefore, professional science teaching journals appear to be the main media addressing this need by providing teachers with curricular and instructional recommendations for self-directed professional learning and science teacher educators with contemporary resources for the curriculum and instruction courses and for professional development activities. In Canada and the USA, this would fall to the NSTA, which has members and representative regions in both countries, although there are other provincial and state associations that make contributions with their respective conferences and journals.

Science Literacy

The science education reforms in Canada (Common Framework for Science Learning Outcomes; Council of Ministers of Education, Canada [CMEC] 1997) and the USA (Science for All Americans; American Association for the Advancement of Science [AAAS] 1990, 1993; National Science Education Standards [NSES], NRC 1996) promote *science literacy for all*, constructivist teaching, and authentic assessment (Ford et al. 1997). Over the last five decades, various science educators have promoted science literacy, which involves some form of democratic, economic, or social action rationale, but none emphasized the explicit connections between science and language (Arons 1983; Bauer 1992; Hurd 1958; Miller 1983; Shen 1975). There is a lack of a shared definition and understanding of *science literacy for all* across science education communities, curriculum developers, science teachers, and professional associations (Roberts 2007).

We take a sociocognitive view of science literacy as a form of disciplinary literacy being composed of two interacting components: fundamental literacy (reading, writing, and application of the skills) in science discourses and conceptual understanding of science and the scientific enterprise (Norris and Phillips 2003). Our view results in the convergence of the various definitions (i.e., practical, civic, cultural) by facilitating engagement in the public debate about science, technology, society, and environment issues, thereby leading to informed solutions and sustainable actions, which impact on citizenship and economic success (Yore 2011; Yore et al. 2007; Moje 2008; Norris and Phillips 2003). The fundamental literacy and conceptual understanding components of science literacy interact symbiotically where improved fundamental literacy leads to enhanced understanding of science and improved understanding leads to enhanced fundamental literacy (Pearson et al. 2010; Webb 2010; Yore 2011). Furthermore, there are mutually beneficial relationships within both components in which better understanding of the nature of science can improve the conceptual understanding of specific science ideas and improved metacognition leads to enhanced thinking or reading (Fang et al. 2010). The very strong correlations (ranging between 0.78 and 0.88) among reading literacy, mathematics literacy, and science literacy measured by the Programme of International Student Assessment illustrated the potential associations and synergies of these literacies (Anderson et al. 2010).

Language in Learning Science

Some outmoded views of learning do not recognize the importance of learners' prior knowledge, metacognition, language, and reasoning abilities (NRC 2000, 2007). "Students often have limited opportunities to understand or make sense of topics because many curricula have emphasized memory rather than understanding" (NRC 2000, pp. 8–9). These views of learning stress skills and drill, rote content learning, lower-level objective testing, and learners' deficits and do not consider disciplinary literacy, the special importance of written language in doing and learning science, the constructive and persuasive functions of language (speaking–listening, writing–reading, representing–interpreting), and the metacognitive awareness and executive control of learning (Fang et al. 2010; Moje 2008; Veel 1997).

Constructivist learning–teaching approaches recognize the expanded boundaries of learning to more fully consider the nature of science, cognitive sciences, the role of language in learning, the importance of prior knowledge, cultural perspectives, and intuitive reasoning as well as the utilization of these resources to *make* meaning rather than *take* meaning from established sources. The various interpretations of constructivism are distributed along a continuum running from information processing to radical constructivism. A centralist view of learning involves an interpretation that emphasizes a balance of learner-directed and teacher-guided approaches. Effective learning experiences must stimulate—engage, focus, and challenge—learners and scaffold their explorations and self-regulated negotiations with other learners, more expert individuals, and contexts to: (a) make sense of their experience and prior knowledge, (b) formulate tentative ideas and construct representations, and (c) move between the oral, print, symbolic, visual, and physical representations resulting from these negotiations. This has led us to an interactive-constructivist model in which learners construct understanding of science based on their ontological assumptions, epistemological beliefs, prior conceptual and discourse knowledge, concurrent sensory experiences, available information sources, and interpersonal interactions within a sociocultural context.

Discipline-specific language and literacy strategies assume constructivist functionalities as learners access and retrieve prior knowledge, enact beliefs and assumptions, seek additional information from diverse sources, interact with target experiences, conduct inquiries, construct knowledge claims, justify and evaluate ideas, and situate new ideas into existing conceptual networks or modify these networks to accommodate discrepant ideas. Explicit instruction regarding requisite conceptual knowledge or strategic abilities is embedded into authentic science learning and provided as “just-in-time” teaching on an “as-needed basis”.

Research Design

We were interested in determining whether the professional literature commonly read by elementary, middle, and secondary school science teachers in Canada and the USA following the introduction of the national science education reforms reflected principles about evidence-based practice, science literacy that involved fundamental literacy, science understanding, and participation in the public debate about socio-scientific issues and interactive-constructivist learning models. Our search of published NSTA journal articles focused on fundamental science literacy and language in science. A two-part document-analysis approach (Fig. 1)—a general survey of 12 years of publications followed by an in-depth analysis of a stratified random sample of literacy-related articles from three 4-year intervals—addressed the following research questions:

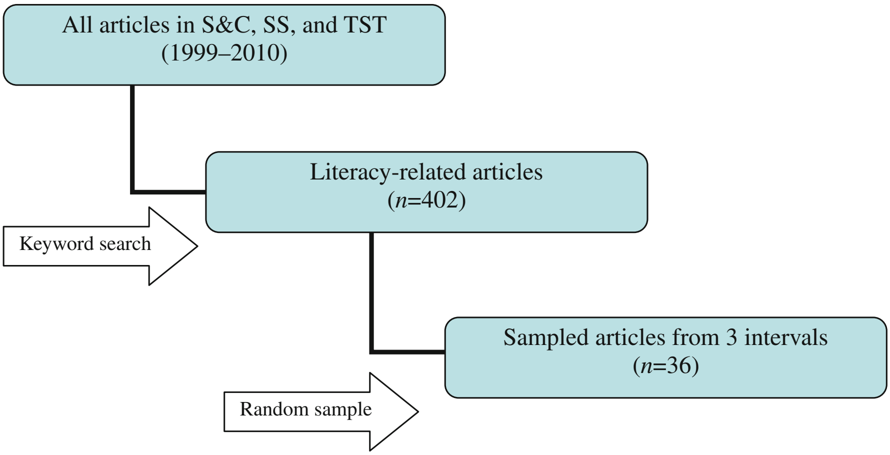

Fig. 1 Sampling process of literacy-related articles in *Science and Children* (S&C), *Science Scope* (SS), and *The Science Teacher* (TST) during 1999–2010

1. What instructional recommendations are made in science teaching journals regarding the literacy component of science literacy?
2. Are these recommendations based on research evidence and the theoretical foundations of science education reforms, learning, teaching, and science literacy?
3. What are the common references utilized to warrant the claims?

Context and Limitations

Literacy-related science articles found in 12 volumes of NSTA science teaching journals (1999–2010) were located, inspected, and analyzed. Based on popularity in and authors from both Canada and the USA, *Science and Children* (S&C, grades K–7), *Science Scope* (SS, grades 6–9), and *The Science Teacher* (TST, grades 9–12) were selected as the representative science teaching journals for this study. The period 1999–2010 was identified as a key period after the onset of the science education reforms in Canada (CMEC 1997) and the USA (AAAS 1990; NRC 1996) and as a sufficient length to monitor the ongoing influences of *science literacy for all*.

Data Collection and Interpretation

Literacy-related articles in the three NSTA journals from the target period were identified using keywords (e.g., science literacy, reforms, language, reading, writing, literacy, literature, drama) and article titles. The articles were read to determine whether the content actually related to the focus of this study; 3–5 % of the keyword/title-identified articles were determined to be unrelated to the study's focus and were deleted from further analysis. The retained articles were read and summarized by the authors and a research assistant; a brief synopsis and reaction was produced for each article. All articles were classified according to their target language activity, literacy focus (reading, writing, English language learning [ELL], etc.), and school level (i.e., elementary, middle, secondary) using 10 established categories (Hand et al. 2010):

1. *Argument and discussion articles* involved large-group and small-group interactions and deliberations, debate, and argumentation (data, backings, warrants, evidences, claims, counterclaims, and rebuttals).
2. *Assessment articles* involved the use of standards assessed for science literacy and understanding, national benchmarks, and formative and summative assessment strategies.
3. *Cross-curricular strategy articles* included those that made specific links to other disciplines (music, social studies, mathematics, language arts).
4. *ELL, vocabulary, and special needs articles* reflected a collection of recommended instruction focused on learning science from a second language perspective, development of terminology, and addressing the special learning needs of students.
5. *Multiple literacy strategies*[1] *articles* reflecting the national reform efforts were classified under this category and combined reading, writing, and oracy, which did not fall neatly into another grouping, and/or spoke to science literacy as the nature of science, science as inquiry, science as a human endeavor, roles of scientists, and science literacy as a broad, undefined idea.
6. *Questioning articles* involved students developing their own focus, investigation, or project questions as the major issue; however, classroom questioning may be embedded in other articles for setting purpose for reading, focusing discussions, promoting inquiry, and constructing understanding.
7. *Reading articles* involved reading strategies (working with textbooks, Know–Want to know–Learned [KWL] charts, general reading strategies to enhance reading comprehension) and using children's literature and trade books to enhance inquiries.
8. *Speaking, listening, and drama articles* involved role-plays (simulating bees in a beehive, scientists, cell organelles, protons, neutrons, electrons) and verbal communication activities to improve students' abilities to express themselves creatively and clearly.
9. *Technologies, Internet, and media articles* involved the use of external resources as an information resource for inquiries, projects, and knowledge; application of information communication technologies in teaching and learning; and use of media, videos, and television series.
10. *Writing articles* involved writing strategies in science, journals, notebooks, and writing effective laboratory reports. (pp. 54–55)

Specifics noted were author affiliations (university, school, other), the focus and connection to science literacy (intertextuality), theoretical foundations and backings

[1] General science literacy was used in Hand et al., 2010. Here we use *multiple literacy strategies* to better reflect the prevalence of articles presenting more than one literacy focus.

for the argument and claims made (recommendations), and the type and nature of the references (empirical research, theoretical positions, research journals, teacher journals and books, other practical sources, etc.) used to justify the recommended practice(s).

Once the literacy and science articles were identified and classified according to their central focus, they were grouped into 4-year intervals (1999–2002, 2003–2006, 2007–2010). Next, a stratified random sample (Fig. 1) was selected from the four most popular categories (writing, reading, multiple literacy strategies, and cross-curricular connections) across the three journals and the three 4-year intervals, resulting in 12 articles (4 topics × 3 intervals) for each journal totaling 36 articles (12 × 3 journals). The most popular categories—although not fully representing the six language arts (US National Council of Teachers of English and International Reading Association, 1996; speaking, listening, writing, reading, representing, interpreting)—were used for research and ethical reasons: providing a large enough pool of articles for each journal to allow the selection to be random and that the selected articles would not be easily identified. The researchers read again the 36 articles to (a) confirm the authors' affiliation (university professor, graduate student, teacher, others—department/ministry of education staff, nongovernmental public awareness of science agent, professional development provider, etc.); (b) ensure the focus of the recommendations; and (c) document connections to the reform documents, learning theories, definitions of science literacy, and number and type of references used as evidence to justify the recommendations. Quality of evidence was determined by the authors as *inadequate* (no connections or weak connections in which implicit or explicit links were made to some foundational materials [e.g., learning theory, science literacy, reforms, or other professional resources] but not empirical qualitative or quantitative research or high-quality scholarship) or *adequate* (reasonable or strong connections were explicit to foundational materials [e.g., learning theory, science literacy, reforms, or professional resources] and to research and high-quality scholarship [e.g., general literacy or science education research journals and academic handbooks or books]).

Results

The results will be reported for the general survey first and for the in-depth analysis second. The results are organized with the authors' assertion as the lead sentence of each paragraph followed by the authors' interpretation of the data as evidence for the assertion. Results address the general trends across all NSTA journals and for each separate journal to detect any school-level differences.

General Results

Our search of all 1999–2010 issues of *Science and Children* (S&C), *Science Scope* (SS), and *The Science Teacher* (TST) revealed that language in science teaching is a reasonably popular theme with 402 articles identified (Table 1). The annual mean number of articles in these journals was 33.5 with a range of 17–91. Each journal had considerably more literacy-related articles in 2010 than in previous years: S&C had 43, SS had 24, and TST had 24. The four most popular areas were multiple literacy strategies ($n = 80$), reading ($n = 80$), writing ($n = 68$), and cross-curricular strategies ($n = 62$). There were slight variations in frequencies of the top three categories across the three journals. In TST, cross-curricular strategies were the eighth most popular theme following multiple literacy strategies; writing; reading; technologies, Internet, and media; ELL, vocabulary, and special needs; assessment; and argument and discussion. Inspection of Table 1 reveals steady or decreased popularity of some areas across the 12 years (questioning; speaking, listening, and drama) and increased popularity for other areas (argument and discussion; assessment; ELL, vocabulary, and special needs). These changes are also reflected in the popularity of these areas in literacy and science education research to some degree, where once popular oral interactions and classroom questioning techniques are no longer of great research interest and where other areas (e.g., argumentation, assessment, and special needs) have enjoyed increased research interest.

Language in science was most popular in the elementary school-level journal followed by the middle and secondary school-level journals. Over the 12-year period, S&C contributed 165 articles with an annual mean of 13.8 and a range of 3–43; SS contributed 138 articles with an annual mean of 11.5 and a range of 2–24;

Table 1 Identified Articles involving Language in Three NSTA Journals for Three 4-year Intervals over the 12-year Period 1999–2010

Category	S&C[a]			SS[b]			TST[c]			Total
	99-02	03-06	07-10	99-02	03-06	07-10	99-02	03-06	07-10	
Argument and discussion	0	0	5	2	0	4	2	0	4	17
Assessment	0	1	6	2	1	3	3	2	2	20
Cross-curricular	11	7	8	8	9	14	3	1	1	62
ELL, vocabulary, special needs	1	6	3	0	1	2	2	4	4	23
Multiple literacy strategies	9	10	15	5	6	15	7	6	7	80
Questioning	0	1	8	0	0	0	1	0	1	11
Reading	4	14	18	5	8	15	3	2	11	80
Speaking and listening, drama	1	0	4	1	1	0	1	0	0	8
Technologies, media, Internet	3	1	3	8	0	6	1	0	11	33
Writing	4	10	12	6	14	2	6	4	10	68
Total	33	50	82	37	40	61	29	19	51	402

[a] Science and Children

[b] Science Scope

[c] The Science Teacher

and TST contributed 99 articles with an annual mean of 8.3 and a range of 1–24. As previously noted, each journal had considerably more articles in 2010 than their respective annual means for 1999–2009. The total number and the average mean number of articles for each journal as well as the number and focus of special issues reflected the readership, the priority of the journal, and the school level. Our research indicated that elementary schools emphasize integration of language arts with most subjects, middle schools emphasize the need to build discipline-specific literacy involving meaning-making and production strategies, and secondary schools emphasize inquiry and content knowledge. These results are reflective of the integrated day in elementary schools, core subjects and special explorations in middle schools, and discipline-specific specialization in secondary schools.

Most authors (60 %) were from universities, a sizeable number (33 %) were from schools (e.g., classroom teachers, administrators, etc.), and a small number (7 %) from other backgrounds (e.g., consultants, artists, professional authors, etc.). S&C had the highest percentage of authors from universities (64 %) and the lowest percentage of school-based authors (27 %). SS and TST had comparable percentages of university-affiliated (60 and 54 %, respectively) and school-based authors (38 and 37 %, respectively).

Authors used a reasonably consistent format (brief introduction, background, descriptive procedures, handouts, closing remarks, visuals, and references) for an array of language strategies, practices, tasks, or ideas connected to high-profile issues or education priorities. NSTA's (n.d.) information for authors provides a prescriptive template for prospective authors; because of the 2,000-word limit for manuscripts, the contributions for these journals are short articles. There were no specifications or limits for the number and type of references, but the information for authors states that articles should not become weighed down with references to the work of others (NSTA, n.d.) in the introduction, implying that introductions may not require references and thus appearing somewhat contrary to establishing a firm and compelling theoretical and empirical foundation for any recommendation made and addressing the IES's call for evidence-based best practices.

Science teaching articles overwhelmingly focused on teaching strategies (94 %) with only a small percentage (6 %) reporting research findings. However, there was some variation across the journals with the surprising finding that the elementary school journal had about a two times higher percentage of empirical research reports (9 %) than the middle and secondary school journals (4 and 6 %, respectively). The central language foci of articles involved argument and discussion (4 %); assessment (5 %); cross-curricular connections (15 %); ELL, vocabulary, and special needs (6 %); multiple literacy strategies (20 %); questioning (3 %); reading (20 %); speaking, listening, and drama (2 %); technologies, media, and Internet (8 %); and writing (17 %). Again, the frequency of these categories varied across the three journals.

Most (>62 %) articles justified their recommendations with a mention of the science education reforms and the national standards (specified in the information for authors), reflecting the impact of the NSES in the USA and the S&C editors' efforts to establish this reform as a national standard and to influence professional practice in science teaching with explicit links to specific standards (>92 % of the articles). Unfortunately, the corresponding reform—Pan-Canadian Common

Framework of Science Learning Outcomes—was not mentioned by Canadian authors. Fewer articles were anchored to other recommended professional practices (~45 %) or empirical research findings (~35 %). The theoretical foundations used in about 12 % of articles involved well-known models of learning (cognitive psychology, multiple intelligences, constructivism, Reggio Emilia), theorists (Dewey, Maslow, Piaget, Vygotsky), or teaching approaches (learning cycles, inquiry, out-of-school experiences). An additional small number of articles (~4 %) were anchored to established definitions of science literacy. Again, the theoretical foundations and justifications varied across the three journals.

Further analysis of the justification and evidence for the recommendations revealed that most references augmented, anchored, or elaborated the central ideas with the authors' (self-citation) and other people's reports, testimonials, or opinions about classroom strategies and practices; a few references utilized the authors' and other people's empirical research, education theory, and reform standards linking the central ideas to public policy or empirical evidence. Some references more fully illustrated the strategies, procedures, and resources used (e.g., teaching with newspapers, specific trade books, movies). Specific references to research journals (301), professional journals (317), books (1,495), reform standards (312), conference papers (21), websites (430), and other sources (77) attempted to build an external foundation of research findings, classroom applications, and testimonials to justify the effectiveness of the recommended practices. However, most articles referenced other practical sources, such as NSTA journals, other teacher journals, teaching methods books, resources, and reports.

Surprisingly, the most highly regarded science teacher education journal (*Journal of Science Teacher Education*) and science education journals (*International Journal of Science Education, Journal of Research in Science Teaching, Science Education*) were not referenced frequently (~20 % articles with 94 citations) as support for evidence-based practices. Twice as many (~40 % articles with 207 citations) of the language in science articles referenced literacy, reading, and general educational research journals rather than science education research journals (*Journal of Educational Psychology, Reading Research Quarterly, Journal of Reading, Review of Educational Research, Educational Researcher, Contemporary Educational Psychology, Cognitive Psychology, Cognitive Science*). Books other than the reform documents (research, practical, trade and children's literature, university textbooks) were used to justify, elaborate, or illustrate the language in science recommendations. Several science literacy strategies claimed to be supported by the *science literacy for all* goal, but did not explicitly define how their recommendations directly link to the appropriate NSES content and teaching standards (S&C was an exception, making direct links to the standards under a specific editorship). Websites are becoming a growing foundation, elaboration, and illustration of recommended approaches.

In-depth Results

An in-depth analysis of the stratified random sample of 36 science literacy articles on writing in science, reading in science, multiple literacy strategies, and cross-curricular connections found within the 1999–2002, 2003–2006, and 2007–2010 intervals confirmed the general trends revealed in the first part of the study. The recommendations varied considerably in their focus within each category, connections to contemporary learning theory, science education reforms, science literacy, and the degree and quality of evidence to support their claims. Most recommendations seemed reasonable on the surface (e.g., language and literacy activities embedded in science is a good thing.), while others extended the boundaries of science instruction (e.g., diverse activities like poetry and drama improve science achievement). The connections to contemporary learning theories and reforms were somewhat inadequate. We found that few articles identified the specific theory or model of learning that was used as a foundation for the recommendation. S&C provided specific links to NSES content and teaching standards, while SS and TST did not always provide such connections. Most articles, either implicitly or explicitly, linked recommendations to dominant classroom practice in elementary, middle, and secondary schools (e.g., inquiry, learning cycles, cooperative learning).

The connections to qualitative and quantitative research, high-quality scholarship, and established expertise that addressed EBP were somewhat disappointing regardless of the authors' affiliation. The authors' affiliation and coded evidence (none, weak, reasonable, or strong) contained in the article and its references were then classified into two summary categories (Table 2): *inadequate* (none or weak evidence—referenced other teaching articles, self-citations, instructional resources, non-peer-reviewed journals, methods textbooks, etc.) and *adequate* (reasonable and strong evidence—referenced a combination of handbooks, academic reports, national reform documents, peer-reviewed research journals, highly regarded scholarship, etc.). These categories did not use the IES criteria for standards of quality evidence mentioned earlier (Shelley 2009).

Many articles (~70 %, 25 of 36) with inadequate evidence were based on very fuzzy evidence, specific and narrow personal opinions or professional experiences, and word of mouth. This was most commonly illustrated by referencing other professional magazines and popular teacher books, which neither receive rigorous peer review nor are based on empirical qualitative, quantitative, and mixed-methods research and high-quality scholarship, and in some cases, books written by the authors themselves (self-citation). A minority of articles (~30 %, 11 of 36) with adequate evidence referenced highly regarded reference books and academic handbooks in literacy and language education, learning theory and psychology, established definitions of science literacy, and empirical research journals in literacy, language, cognition, and science education. Surprisingly, there did not appear to be a pattern in the quality of evidence for authors with different affiliations (university professors compared to all other authors).

We found variations in the quality of evidence across the three journals, the three 4-year intervals, and the four popular categories. The journals had 25–41.7 % adequate evidence for the recommendations in the articles analyzed. There was variation in evidence across the 4-year intervals for S&C (0–50 %), SS (0–75 %), and TST (0–50 %). The variations in the quality of evidence revealed the highest quality for reading and multiple literacy strategies (both 44.4 % adequate), which appears to reflect the long history and availability of research on content area

Table 2 Authors' Affiliation and Quality of Evidence for Three NSTA Journals by 4-year Intervals (1999–2010) for the Random Sample of 36 Articles Selected from the Four Most Popular Language in science Topics

Category	S&C[a]			SS[b]			TST[c]			Quality of evidence (%)
	99–02	03–06	07–10	99–02	03–06	07–10	99–02	03–06	07–10	Inadequate/Adequate
Writing	U–W	U/T–N	U/T–N	T–R	T/O–N	U–R	T–N	T–N/W	U–N	77.8/22.2
Reading	U–W	U–R	T/U–N/W	U–S	T/U–N	U–W	U/T–R	U/T–N/W	U/O–R/S	55.6/44.4
Multiple literacy strategies	U–R	U/O–R	G/T–N	U/O–R	T–N	U–R	U–W	U–N/W	U–W	55.6/44.4
Cross-curricular connection	U/G–W	U–N	T/U–N/W	T–N	T–W	T–W	T–N	T-N	U–R/S	88.9/11.1
Subtotal (%) inadequate/adequate by interval	75/25	50/50	100/0	25/75	100/0	50/50	75/25	100/0	50/50	
Total (%) inadequate/adequate by journal	75/25			58.3/41.7			75/25			69.4/30.6

Authors' affiliation: *U* university professor, *T* teacher, *G* graduate student, *O* other type of educator. Levels of evidence: *N* no evidence, *W* weak evidence, *R* reasonable evidence, *S* strong evidence, *N/W* inadequate evidence, *R/S* adequate evidence

[a] Science and Children

[b] Science Scope

[c] The Science Teacher

reading and the use of multiple literacy strategies in science teaching. The quality of evidence (22.2 % adequate) for writing in science did not appear to reflect the increasing quantity and quality of research in writing-to-learn science. The surprising finding was the low quality of evidence (11.1 % adequate) for cross-curricular connections or integration of disciplines for the articles examined.

We looked closely at the most recent articles to detect any new trends not observed in the general survey or the 4-year intervals. The data collected from the 2010 articles from the three journals revealed some changes from the 1999–2009 data. Overall, the number of literacy-related articles is considerably greater than for any other year, 91 in 2010 compared to an annual range of 21–49 for 1999–2009. The 2010 journal articles tended to be longer than in the 1999–2009 period, possibly due to inclusion of more figures, tables, and images. Also, with some variance across the three journals, the percentage of authors from schools decreased, while authors from universities and outside agencies increased. References to learning models, definitions of science literacy, and science education reforms remained low. Within S&C and SS, all of the 2010 articles shared teaching strategies; none were reports of empirical research. Only one 2010 literacy-related article in TST reported empirical research.

Closing Remarks

Knowledge transfer or mobilization in terms of influencing educational policy and providing an evidence basis for professional practice continues to gain importance; however, the North American science education communities do not appear to be taking these calls seriously (DeBoer 2011; Fang et al. 2010). The impact of NSTA journals is significant as demonstrated by the organization's membership, presence of the journals in many staff rooms and resource centers, and use in teacher education courses.

Scientific Literacy and an Interactive-Constructivist Model of Science Learning

Many of the recommended practices related to the fundamental literacy component of science literacy are likely valuable, which would be possible to judge were there a common shared definition of science literacy. In the case of the journals examined in this study, many of the recommendations are not anchored or justified with high-quality evidence required by the best practices movement. It was difficult to judge the validity of most instructional recommendations and to sort out valid practices from "cute" ideas that did not connect to the target learning outcomes. This placed heavy demands on teachers' backgrounds and critical reflections about science instruction and resources with which they were not familiar.

We found that most of the recommendations could be more adequately supported by contemporary interactive-constructivist models of learning (NRC, 2000, 2007), science education reforms (AAAS 1990, 1993; CMEC 1997; NRC 1996), contemporary definitions of science literacy (Norris and Phillips 2003; Yore et al. 2007), role of language in learning and doing science (Carlsen 2007; Fang 2005, 2006; Fang and

Schleppegrell 2010; Fang et al. 2010; Osborne 2010; Pearson et al. 2010; Webb 2010; Yore et al. 2003), scholarship about disciplinary literacy (Moje 2008; Shanahan and Shanahan 2008), and growing empirical research on language arts in doing and learning science (2006 Special Issue of the *International Journal of Science Education*, 2009 and 2010 Special Issues of *Research in Science Education*, 2007 and 2010 Special Issues of the *International Journal of Science and Mathematics Education*).

Most articles did not link science literacy with fundamental literacy. Instead, literacy was presented traditionally as reading, reading comprehension, writing, and oracy focused on taking meaning or communicating existing knowledge rather than making meaning and constructing understanding from and with texts. Few articles substantiated the interactive and constructive aspects of making meaning and constructing understandings where language shapes what is known as well as reports what is known. Many articles provided recipe-type lessons without the substantive foundations and evidence that allow for a professional rationale and justified choice.

Interestingly, one recommendation, found in the in-depth random sample and first made in 1999 with weak evidence to support the emergent innovation, has grown to be a well-documented approach (Hand and Keys 1999). The authors of this original article justified the innovation on their understandings, experiences, opinions, and speculations about writing-to-learn science and their disappointment with traditional approaches to laboratory reports. However, they—and others—moved their research agenda from small case studies to meta-analyses, meta-syntheses, large-scale professional development projects, and finally to a random control trial, which is the Gold Standard of current research approaches (Gunel et al. 2007; McDermott and Hand 2010). This 10-year program of study illustrates what science education researchers should do to move ideas into classroom practice and to influence educational policy.

Bridging the Theory–Practice Gap

It should be noted that *Science and Children* ran a special column in volumes 44 through 46 (2006–2009) entitled “Perspectives.” Here, the authors presented research, most often directly related to the theme of the issue and to S&C readers. Topics included inquiry-based learning, reading and writing in science, assessment, and cultural diversity in the science classroom. While it is admirable that the effort was made to include a specific research component in the journal, there are problems with its inclusion that must be spoken to. The column ran two pages in length and was typically placed toward the end of the issue. These physical limitations could be seen to communicate a lesser value on the inclusion of research in the journal. Given the often direct connection between the column’s topic and the overall theme of the issue, “Perspectives” might have been placed at the beginning of the issue and directly discussed the theoretical foundations and evidentiary basis of each article in the issue. This might read like a research-focused editor’s message. Most problematic of the presentation of “Perspectives”, however, is its distinct separation from the rest of the journal’s articles. This isolation reinforces the divide between theory and practice rather than infusing theoretical support throughout practical reports and articles. While we recognize the inclusion of these research reports, we do not see them as serving the same role as strong evidence of evidence-based practice.

The NSTA Press publishes and co-publishes a variety of practice-oriented books and position papers for teachers regarding science literacy. Many of these are excellent examples of promoting and justifying evidence-based literacy practices in science teaching. Fang et al. (2010), Norton-Meier et al. (2008), Saul (2004), and others are recent additions to NSTA's book store that could be used as references to justify many literacy activities and strategies involving constructive–interpretative language arts pairs (talking–listening, writing–reading, representing–interpreting) for improving science literacy. Furthermore, these publications illustrate a writing style, theoretical foundation, and referencing approach that appeals to teachers of science as evidenced by these books' sales records. Likewise, the common core standards (Council of Chief State School Officers [CCSSO] and the National Governors Association [NGA] 2010) and new framework for K–12 science education (NRC 2011) recognize and justify the constructive, persuasive, representational, and communicative functions of language in science, engineering, technology, and mathematics practices. These documents should become familiar to practicing teachers and could be used to justify (a) critical habits of mind related to seeking and evaluating information from various print and digital sources, (b) the use of argumentation to make and communicate knowledge claims based in scientific evidence, and (c) visual literacy required to display and interpret data in these disciplines.

Knowledge Production and Transfer

Knowledge production is a cyclic process of writing—peer feedback—revision involving authors, editors, and reviewers that shape what is said as well as how and even if it is said. Knowledge transfer, mobilization, dissemination, and utilization involve moving messages about ideas and innovations to specific end users who may or may not belong to the same discourse community of the originators of the message—in this case, evidence-based practices about science literacy, teachers of science, and authors from various academic and professional communities. Therefore, authors, gatekeepers (editors and reviewers), and readers need to be prepared to monitor, interpret, and critically evaluate the knowledge that is produced and disseminated.

Since science teaching journals are a major resource in self-directed teacher learning and many teacher education and development programs, the authors, editors, and reviewers of these journals should assign higher priority to EBP articles and recommendations linked to contemporary reforms, learning theory, and disciplinary literacy and justified by results from peer-reviewed empirical qualitative and quantitative research, systematic reviews, and secondary analyses (Rossman and Yore 2009). We found that many of the authors were involved in university teacher education programs with access to and awareness of the current research literature in language, literacy, and science education, making provision of an abridged but compelling evidence trace for their recommendations easily done. The writing style, language, length, and focus are relevant to most teachers who read these journals, but information to potential authors should recognize the professional need for evidence-based practices and the ways in which such evidentiary basis can be established (see Millar and Osborne 2009).

Unfortunately, editors and reviewers occasionally dissuade authors from using high-quality scholarly and research references by limiting the number and type of references in practice-oriented articles, warning authors to avoid becoming "bogged down with references to others' research" (NSTA, n.d., p. 3). We believe this position is short-sighted and of questionable professional value. Authors wishing to provide a strong evidence base for their recommendation need to be aware of the end user and audience of such articles and reporting genre and language appropriate to this audience. Other science teaching journals in Australia and the United Kingdom appear to be partially addressing the need for better-quality evidence to justify curricular, teaching, and assessment recommendations involving the language arts in science instruction and resources (Hand et al. 2010). Authors of science teaching articles would be well advised to become familiar with and then reference appropriate handbooks, secondary analyses (meta-analyses, meta-syntheses, systematic reviews), critical research articles and reports, and popularized versions of empirical studies related to their recommendations. The inclusion of a few of these supportive resources would substantiate their recommendations and afford the end user some comfort and confidence in the recommendations' effectiveness.

The results of this study suggest that science teacher educators need to equip preservice and practicing teachers with the critical habit of mind and abilities to critique instructional recommendations in the teaching literature rather than ascribing creditability based solely on publication or sponsoring agency. One way to do this in organized and self-directed professional learning for science teachers is to encourage teachers to construct brief (1-page) reaction papers. The reaction paper should consist of a summary of the teaching article ($\sim$125 words) that retains the voice and stance of the article's author and a critical analysis of the recommendation ($\sim$120 words) based on the teacher's explicit model of learning, definition of the desired goal, and preferred instructional approach—in our case, this would be the interactive-constructivist model of learning, scientific literacy, inquiry teaching, and authentic assessment. These reaction papers will provide the theoretical foundation and evidentiary based that was lacking in most articles examined.

References

Adey, P. S., & Shayer, M. (1990). Accelerating the development of formal thinking in middle and high school students. *Journal of Research in Science Teaching, 27*(3), 267–285.

American Association for the Advancement of Science. (1990). *Science for all Americans: Project 2061*. New York, NY: Oxford University Press.

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy: Project 2061*. New York, NY: Oxford University Press.

Anderson, J. O., Chiu, M.-H., & Yore, L. D. (2010). First cycle of PISA (2000–2006)—International perspectives on successes and challenges: Research and policy directions [Special Issue]. *International Journal of Science and Mathematics Education, 8*(3), 373–388.

Arons, A. B. (1983). Achieving wider scientific literacy. *Daedalus, 112*(2), 91–122.

Bauer, H. H. (1992). *Scientific literacy and the myth of the scientific method*. Champaign, IL: University of Illinois Press.

Black, P. J., & Wiliam, D. (1998). *Inside the black box: Raising standards through classroom assessment*. London: King's College.

Carlsen, W. S. (2007). Language and science learning. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 57–74). Mahwah, NJ: Lawrence Erlbaum.

Council of Chief State School Officers and National Governors Association. (2010). *Common core state standards for English language arts & literacy in history/social studies, science, and technical subjects*. Available from http://www.corestandards.org/assets/CCSSI_ELA%20Standards.pdf.

Council of Ministers of Education, Canada. (1997). *Common framework of science learning outcomes, K to 12: Pan-Canadian protocol for collaboration on school curriculum*. Toronto: Council of Ministers of Education.

DeBoer, G. E. (Ed.). (2011). *The role of public policy in K-12 science education*. Charlotte, NC: Information Age Publishing.

Fang, Z. (2005). Scientific literacy: A systemic functional linguistics perspective. *Science Education, 89*(2), 335–347.

Fang, Z. (2006). The language demands of science reading in middle school. *International Journal of Science Education, 28*(5), 491–520.

Fang, Z., Lamme, L. L., & Pringle, R. M. (2010). *Language and literacy in inquiry-based science classrooms, grades 3–8*. Thousand Oaks, CA: Corwin/NSTA Press.

Fang, Z., & Schleppegrell, M. J. (2010). Disciplinary literacies across content areas: Supporting secondary reading through functional language analysis. *Journal of Adolescent & Adult Literacy, 53*(7), 587–597.

Ford, C. L., Yore, L. D., & Anthony, R. J. (1997, March). *Reforms, visions, and standards: A cross-curricular view from an elementary school perspective*. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Oak Brook, IL. (ERIC Document Reproduction Service No. ED406168).

Gunel, M., Hand, B., & Prain, V. (2007). Writing for learning in science: A secondary analysis of six studies. *International Journal of Science and Mathematics Education, 5*, 615–659.

Hand, B., & Keys, C. (1999). Inquiry investigation. *The Science Teacher, 66*(4), 27–29.

Hand, B., Yore, L. D., Jagger, S., & Prain, V. (2010). Connecting research in science literacy and classroom practice: A review of science teaching journals in Australia, the UK, and the United States, 1998–2008. *Studies in Science Education, 46*(1), 45–68.

Hayward, D. V., & Phillips, L. M. (2009). Considering research quality and applicability through the eyes of stakeholders. In M. C. Shelley II, L. D. Yore, & B. Hand (Eds.), *Quality research in literacy and science education: International perspectives and gold standards* (pp. 139–148). Dordrecht: Springer.

Hurd, P. D. (1958). Science literacy: Its meaning for American schools. *Educational Leadership, 16*, 13–16 & 52.

McDermott, M. A., & Hand, B. (2010). A secondary reanalysis of student perceptions of non-traditional writing tasks over a ten year period. *Journal of Research in Science Teaching, 47*, 518–539.

Millar, R., & Osborne, J. (2009). Research and practice: A complex relationship? In M. C. Shelley II, L. D. Yore, & B. Hand (Eds.), *Quality research in literacy and science education: International perspectives and gold standards* (pp. 41–61). Dordrecht: Springer.

Miller, J. D. (1983). Scientific literacy: A conceptual and empirical review. *Daedalus, 112*(2), 29–48.

Moje, E. B. (2008). Foregrounding the disciplines in secondary literacy teaching and learning: A call for change. *Journal of Adolescent & Adult Literacy, 52*(2), 96–107.

National Science Teachers Association. (n.d.). *Right from the start*. Retrieved from http://www.nsta.org/pdfs/writestart.pdf.

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education, 87*(2), 224–240.

Norton-Meier, L., Hand, B., Hockenberry, L., & Wise, K. (2008). *Questions, claims and evidence: The important place of argument in children's science writing*. Portsmouth, NH: Heinemann/NSTA Press.

Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse [Special Issue]. *Science, 328*(5977), 463–466.

Pearson, P. D., Moje, E. B., & Greenleaf, C. (2010). Literacy and science: Each in the service of the other [Special Issue]. *Science, 328*(5977), 459–463.

Roberts, D. A. (2007). Scientific literacy/science literacy. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 729–780). Mahwah, NJ: Lawrence Erlbaum.

Rossman, G. B., & Yore, L. D. (2009). Stitching the pieces together to reveal the generalized patterns: Systematic research reviews, secondary reanalyses, case-to-case comparisons, and metasyntheses of qualitative research studies. In M. C. Shelley II, L. D. Yore, & B. Hand (Eds.), *Quality research in literacy and science education: International perspectives and gold standards* (pp. 575–601). Dordrecht: Springer.

Rowe, M. B. (1974). Wait-time and rewards as instructional variables, their influence on language, logic, and fate control: Part I - Wait-time. *Journal of Research in Science Teaching, 11*(2), 81–94.

Saul, E. W. (Ed.). (2004). *Crossing borders in literacy and science instruction: Perspectives on theory and practice*. Newark, DE: International Reading Association/National Science Teachers Asssociation.

Shanahan, T., & Shanahan, C. (2008). Teaching disciplinary literacy to adolescents: Rethinking content-area literacy. *Harvard Educational Review, 78*(1), 40–61.

Shelley, M. C, I. I. (2009). Speaking truth to power with powerful results: Impacting public awareness and public policy. In M. C. Shelley II, L. D. Yore, & B. Hand (Eds.), *Quality research in literacy and science education: International perspectives and gold standards* (pp. 443–466). Dordrecht: Springer.

Shen, B. S. P. (1975). Science literacy: The public understanding of science. In S. B. Day (Ed.), *Communication of scientific information* (pp. 44–52). New York, NY: S. Karger.

United States Institute of Education Sciences. (2003). *Identifying and implementing educational practices supported by rigorous evidence: A user friendly manual*. Washington, DC: Author.

United States National Council of Teachers of English & International Reading Association. (1996). *Standards for English language arts*. Urbana, IL & Newark, DE: Authors.

United States National Research Council. (1996). *The national science education standards*. Washington, DC: The National Academies Press.

United States National Research Council. (2000). *How people learn: Brain, mind, experience, and school—Expanded edition*. Committee on Developments in the Science of Learning. J. D. Bransford, A. L. Brown, & R. R. Cocking (Eds.). Commission on Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

United States National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K-8*. Committee on Science Learning, Kindergarten through Eighth Grade. R. A. Duschl, H. A. Schweingruber, & A. W. Shouse (Eds.). Board on Science Education, Center for Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

United States National Research Council. (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. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press. Available from http://www.nap.edu/catalog.php?record_id=13165.

Veel, R. (1997). Learning how to mean—scientifically speaking: Apprenticeship into scientific discourse in the secondary school. In F. Christie & J. R. Martin (Eds.), *Genre and institutions: Social processes in the workpace and school* (pp. 161–195). London: Cassell.

Webb, P. (2010). Science education and literacy: Imperatives for the developed and developing world [Special Issue]. *Science, 328*(5977), 448–450.

Yore, L. D. (2011). Foundations of scientific, mathematical and technological literacies—Common themes and theoretical frameworks. In L. D. Yore, E. Van der Flier-Keller, D. W. Blades, T. W. Pelton, & D. B. Zandvliet (Eds.), *Pacific CRYSTAL centre for science, mathematics, and technology literacy: Lessons learned* (pp. 23–44). Rotterdam: Sense.

Yore, L. D., Bisanz, G. L., & Hand, B. (2003). Examining the literacy component of science literacy: 25 years of language arts and science research. *International Journal of Science Education, 25*(6), 689–725.

Yore, L. D., Pimm, D., & Tuan, H.-L. (2007). The literacy component of mathematical and scientific literacy [Special Issue]. *International Journal of Science and Mathematics Education, 5*(4), 559–589.