Article

'Scientific Literacy': An Exercise in Model Building

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Abstract: 'Literacy' and 'science' are power words and the interaction between them is of potential interest to people working at other boundaries between text and content, such as that characterising wider disciplinary literacy. 'Scientific literacy' has a deep enough literature base to support an attempt to build a model of these interactions. If robust, such a model could synthesise existing literature and resolve differences within a narrower range of journals. This quantitative review suggests such a model based on a wide review of previous literature and then challenges it by comparing publication patterns in premium international journals dealing specifically with research in science education. The emergent model comprises interaction between *Use of*, *Engagement with* and *Access to* science and its application revealed changes in publication patterns both within and between the five science education research journals surveyed. The use of power words can obscure, rather than clarify, discussions that lead to curriculum and pedagogical decisions. Robust models can resolve multiple components of a complex field and make it easier to understand for newcomers, easier to explain when change seems necessary to those more deeply involved, and then expedite the prediction of fruitful areas for further work.

Keywords: disciplinary literacy; science literacy; model; review; reading; writing

1. Literacy as a Power Word

Words carry weight as well as meaning, and choices between them reflect a desire to communicate status as well as information. Shifting terminology often reveals changes in perceived status over time. The wish to have colleagues recognise the importance of the things that we value need not involve malice, but this common phenomenon can lead to use of the same labels to represent completely different things, or to use of different labels for things that are substantially similar. Earlier labels can survive in the presence of later ones, further complicating contemporary discussion.

The repeated emergence of the word 'literacy' in curriculum deliberations illustrates its power. For example, Australia began the second decade of this millennium with another attempt at a national curriculum. The debate leading up to the release of the English; Mathematics; History and Science curricula included the following contribution from the Australian Science Teachers Association (ASTA).

> The ASTA rejects in the strongest possible terms the notion that the term 'literacy' is one that should be preserved only for use in the study of English and it's Literacy Continuum. The term has been increasingly and successfully employed across a broader range of curriculum areas. Apart from 'scientific literacy', the applications to 'financial literacy', 'numerical literacy', 'visual literacy' and others are commonplace and widely understood and accepted in education circles. [1]

Tensions in usage can slide into actual controversy between subject areas. This phenomenon has a long history within science itself, with implications for science education. This makes science education a fertile ground for the development of a model that could clarify discussions of literacy in other disciplines.

2. Expanding Notions of Literacy

The Shorter Oxford Dictionary defines the Middle English adjective *literate* as "acquainted with letters". 'Literate' gave rise to 'illiterate' in the 1550s, hence 'illiteracy' in the 1660s and 'literacy' in the 1880s. The expansion of meaning did not stop in the nineteenth century and today literacy has a range of meanings. Describing a person as literate, in its fundamental sense, may mean that they can read and write or, in its earliest derived sense, it may mean that they are educated, cultured and critical [2]. In the more recent sense of discipline literacy, it may mean that they can operate meaningfully within one or more fields of knowledge [3].

Literacy can describe activities as diverse as engagement with novel experience [4]; video games [5]; situated cultural responses [6]; conceptual understanding [7]; metacognitive awareness [8]; identity [9]; reading and writing [10], and media awareness [11].

The fundamental sense of basic literacy usually means the ability to read and write in a particular language [12]. Insertion of different adjectives indicates various derived meanings, for example: visual literacy is the ability to decode, manipulate and criticise images [13]. Arts literacy is the ability to acquire and implement skills in the journey into artistic practice [14]. Cultural literacy is the ability to recognise, interpret and predict the impact of different cultures [15]. Mathematical (or numerical) literacy is the ability to manipulate numbers for analytical and predictive purposes, sometimes synonymous with numeracy and/or data literacy, but sometimes not [16]. Technological literacy is the ability to recognise needs that could be met with technology, design devices that would meet those needs and evaluate such designs (sometimes labelled technacy: [17]). Financial literacy is a composite of knowledge, attitudes and behaviour regarding wealth [18]. Scientific literacy is the focus of this paper and it usually refers to the ability to understand and apply the knowledge that scientists produce. 'Science' is sometimes opposed to 'scientific' in an attempt to separate the two senses but the similarity of the two words encourages interchangeable use within the existing literature and within this paper.

All of these uses are increasingly subsumed under the notion(s) of content and/or disciplinary literacy. This discussion seemed to emerge from concerns within, or about, the community of those who teach English as a separate subject [19]. Doubts about the effectiveness of secondary schooling in preparing students for university courses in science, technology, engineering and mathematics programs has driven this more recent resurgence in a particular jurisdiction [20].

> Various assessments have shown that secondary school students in the United States are not reading well enough to succeed in careers or college, with particular concerns about their readiness to participate in the so-called STEM (Science–Technology–Engineering–Mathematics) professions. [21]

All of this suggests almost inevitable confusion. The literacy labyrinth [22] can be challenging for both newcomers entering the field and for more experienced scholars looking for other work relevant to their own. A robust model of the field might be useful in resolving distinctions between the various legitimate ways in which the word is used.

3. The Role of Models in Intellectual Work

Models can aid in simplification of such contested fields and they have been the subject of considerable work (such as [23,24]). A useful model can reduce a complex set of phenomena to a more readily understandable pattern, suggesting a more adequate explanation, which leads in turn to more focused experimentation or to more appropriate action. A good model aids understanding, a better

model aids explanation, the best model aids prediction and all of them can arise from quantitative data, qualitative data or some mixture of the two.

The human settlement of the scattered islands of the central Pacific provides a concrete example of a quantitative model in action. These islands are far from continents and, often, far from each other. How, and when, people reached them has exercised the imagination of generations [25]. The people themselves have tales of heroic voyaging traditions (consider Disney's 2016 animated film, *Moana*), which were taken fairly seriously in the 18th and 19th centuries.

However, a more sceptical view surfaced by the middle of the 20th century. There were fairly heated disputes between those who continued to accept some form of this voyaging tradition and those who did not. The sceptical group considered canoe trips between mutually visible islands, or to those just over the horizon, to be plausible; but they thought that long voyages that depended on accurate navigation across open ocean were probably impossible. They thought accidental drifting, rather than deliberate voyaging, drove settlement of the scattered islands. Such successful drifting depended on prevailing winds and currents, if it was to lead to life-saving island landfalls. These sceptics were not inclined to place much reliance on local tradition.

Computers made it possible to produce mathematical models that could calculate the probability of such accidental discoveries. Hydrological and meteorological information had been collected to help European navigation both before and since the voyages of Cook (1766–1780) and it made production of a computer model feasible. Such a project ran from 1964 to 1967 and involved the entry of 800,000 separate data points. The computer model made it possible to assume any starting point within the Pacific and calculate the probability of drifting to any other point. Some likely drift paths did emerge (such as from Tonga to Fiji) but no simulated combination of winds and currents took a hypothetical canoe to either Hawaii, New Zealand or Easter Island, the three apexes of the Polynesian Triangle [26]. The model suggests that ancestral Polynesians were more likely to have been deliberate voyagers than they were to have been accidental drifters and provides an example of the potential of quantitative models to resolve contentious issues.

Many forms of intellectual work use models [27]. Modelling can be used in learning contexts, for example through ICT-based conceptual building tasks [28,29]; exploration of student negotiation during model building [30]; or application of student models to quantitative problems [31].

Science provides a rich example of the tension that can arise between multiple meanings of literacy and that contested field offers an opportunity for conceptual model building that may bring clarity to this sometimes-obscure area.

This paper begins that process with a quick review of the literature to establish the boundaries of the field. The analysis provides the basis for synthesis leading to the development of a conceptual model for scientific literacy, based on inferences from that wider literature. Existing data can challenge that model to assess the extent to which it reveals aspects of that data that might not have been visible otherwise.

Such a quantitative approach may seem strange in consideration of literature about reading and writing but the importance of usage in distinguishing meanings is well-established within linguistics [32] and a recent review of specialist literature provides a corpus that may be adequate to support an attempt [33]. Survival through these first challenges could suggest that the model that we develop might be more widely useful.

4. The Case of Science Literacy

Science (or scientific) literacy, as distinct from basic literacy, is usually taken to mean acquaintance with the fundamental ideas of science [34] and the ability to at least interact with, and perhaps evaluate, the work that scientists do and the social impact that follows from it [35]. Interest in scientific literacy has grown as science became more expensive, as public attitudes to it become more critical, and as official support for it came to depend more on economic opportunities than on military/industrial imperatives.

Over past decades, school teachers have become worried about how well pupils were responding to their science classes. University lecturers have become worried about decreasing numbers of pupils choosing science subjects. Industrialists have become worried about decreasing numbers of able scientists and engineers. Governments have become worried about the impact of all of this on economic growth. Chronological consideration of these issues over the past century suggests that widespread response usually lagged recognition of a problem by several decades.

The 20th century began with movement of the children of urban workers into secondary schools to which their parents had not aspired. This led to difficulties in reading their science textbooks and the consequent development of readability formulae [36]. Mid-century brought waves of post-war immigrants to more developed, English-speaking societies. Most of these immigrants did not speak English and the movement of their children into those same schools provoked a consequent resurgence of problems that had surfaced previously [37]. Contemporary decolonisation saw increasing industrialisation in the global South that led to English-medium courses in non-English speaking countries and specific courses to prepare the most able students to study in English-speaking contexts in the global North [38]. The last quarter of the 20th century saw a renewal of concern about the literacy of the general population, partly driven by public events in different jurisdictions [39,40] and partly by shifting patterns of funding for work based on varying theoretical positions [41,42]. The early part of the 21st century saw the emergence of the notion of multi-literacies [43].

Each of these waves of change provoked further broadening use of the word literacy, following renewed realisation of the need for a broad range of students, at a range of educational levels, to understand text produced by science teachers and scientists, to evaluate competing scientific claims and to produce text that accurately reflected the level of their understanding. Contemporary concerns for discipline literacy heighten the pressure on English as a school subject [44]. There has been money available to boost literacy in science but clarity about how such literacy might be understood has been lacking. Consequently, competing groups have attempted to claim an area and demonstrate its distinctive importance. All of this has provided a deep well of literature that could be usefully applied to contemporary discussions of literacy in other specialist areas.

Different people use similar words to talk about different things when discussing science literacy [45,46]. The earliest move was to distinguish between science education (occurring in schools) and science literacy (occurring outside schools). This discussion was particularly intense more than a generation ago [47–50]. Education people have tended to distinguish between formal as opposed to informal education. Museum people and journalists have preferred to distinguish between education and literacy. British writers preferred to label the latter as 'the public understanding of science' while US writers use 'science literacy'. All of these distinctions refer to the same divergent phenomena: learning about science in classrooms with teachers and learning about science beyond the school institution. Some groups of people advocated the application of more resources to school science, while others preferred to recognise past failures and apply resources beyond the school.

Contemporary schooling is compulsory in most developed countries and that made it apparently ideal for achieving higher levels of public understanding. 'Literacy' and 'education' were drawn together so that 'scientific literacy' became code for what science should be taught in schools [51]. This collapse of the two ideas sometimes left aside the question of whether school science should advance the public understanding of science, prepare pupils for future careers in science and engineering, or attempt to do both. Conversely, international tests of science knowledge, such as the Program for International Student Assessment: PISA [52], used the public understanding sense of literacy and consequently popularised that sense.

The linking of literacy to supposedly essential content knowledge produced a response from English teachers who saw it as part of their territory [53,54]. This move was supported by much work in specialist language teaching in universities in non-English speaking countries [55–59] and by concern for the needs of language minority pupils in Anglophone high school classes [60–62]. These people

saw science literacy as the ability to read and write in the language style of school or university science classes and books [63]. This field apparently shifts in response to pressures from multiple directions.

5. Mapping Wider Tensions

This widening reach of 'literacy' can be synthesised into an image of the field that illustrates the tensions between the themes emerging from that broad, generational survey of the literature (see Figure 1).
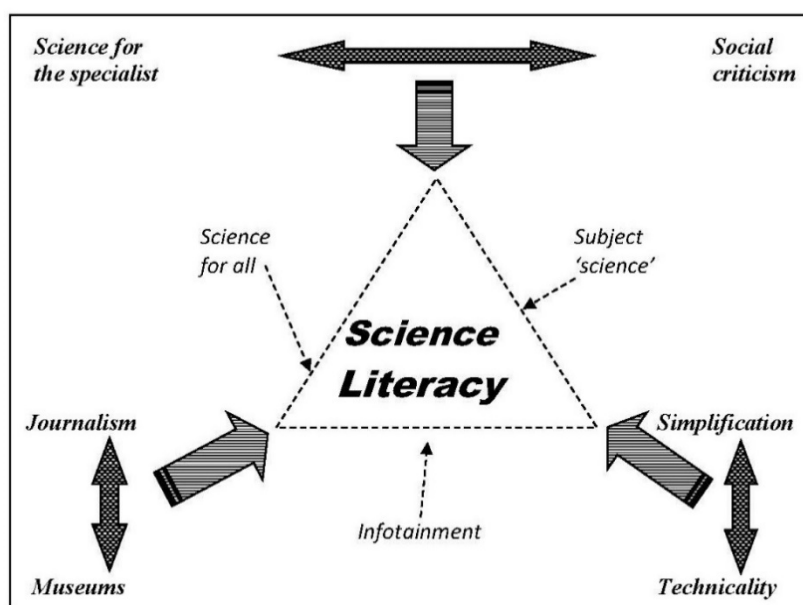

Figure 1. Science Literacy as nodes within wider tensions.

The arrows at the boundaries of Figure 1 represent the impact of tensions between two intentions at any one apex of the field of Science Literacy. The inward arrows represent the apparent tensions acting on the field in question in various ways at different times and in different places, twisting it without collapsing it. These interacting tensions shape approaches to Science for All, on the left face of the triangle; Subject Science, on its right; and Infotainment on its base.

The top apex on Figure 1 represents tension between the economic need for specialist workers [64] and legitimate social criticism [65] and it presses down over the interaction between language and popular science (at the right apex); through various motivations for encouraging the public understanding of science (at the left apex), and perceptions of what that might be [66].

The bottom right apex indicates tension between appreciation of technical language [67] and the contrasting drive for simplification [68] and it stirs up wider literacy issues [69]. The field is further muddied by use of 'communication' both for this phenomenon and for the role of science explainers within technical museums.

Journalism seeks to make scientific technicality understandable and entertaining for a wider public [70,71], while museum staff slide between their archival responsibility to preserve objects for later study and the institutional need to entertain the public who fund such custodial purposes [72,73]. This tension, at the bottom left apex of Figure 1, generates both publication and project funding that drives towards popular science publications [74] and is mediated by science communicators in modern museums.

Different areas of activity move along various sides. Subject science [75] slides between the top and right hand vertices: moving between the use(s) of science and access to science. Infotainment [76] slides between the two vertices at the base of the triangle: moving between engagement with science and access to it. Science for all [77] slides between the top and left hand vertices: moving between

use(s) of science and engagement with it. These activities slide along and inwards depending on the interests and needs of particular writers. Science for all may be closer to the upper apex (if its purpose is closer to building the public understanding of science) or to the left lower apex (if its purpose is closer to building public engagement with science). The specific tensions described above characterise Science. This paper will discuss similar patterns, which may exist for other specialist areas, after further exploring the science context.

6. Conceptual Modelling: An Attempt at Clarity

There may not be much point in arguing about what literacy really means [78] but mapping the uses of the words could clarify some of the tensions and that could be useful. Figure 1 suggests three tensions as forming the particular shape of Science Literacy at any particular place and time. The tension between Science for the Specialist and Social Criticism seems to involve disagreements about the *Use* of Science [79]. The shared and distinct interests of Journalism and Museums seem to revolve around encouraging greater public *Engagement* with Science [80]. Concern for Technicality and a desire for Simplification both seem to involve *Access* to Science [81]. This, in turn, suggests what might be called the Use–Engagement–Access model: *UEnAc* (Figure 2).
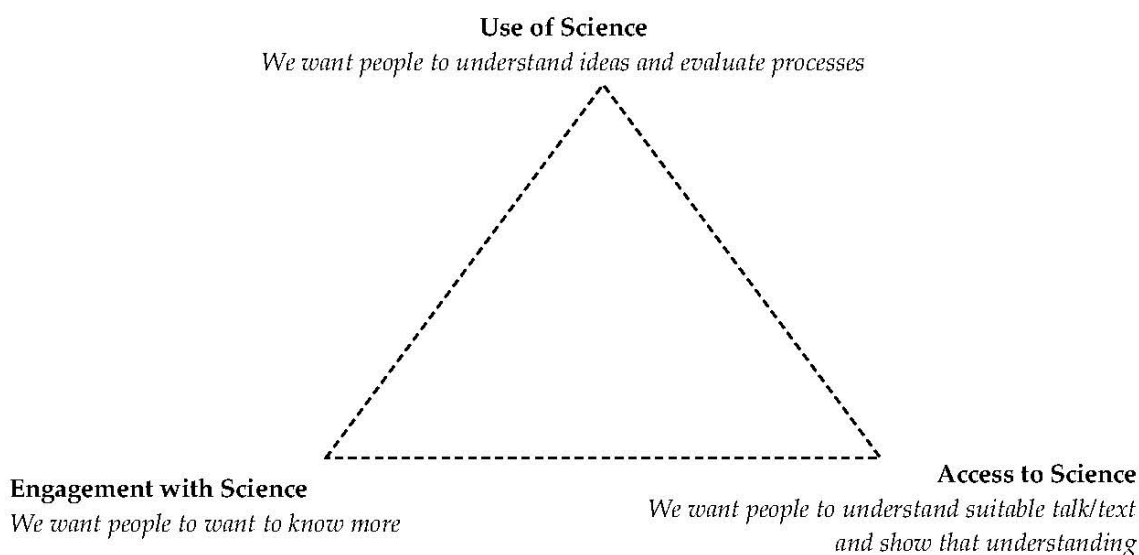

Figure 2. Science literacy as a field in tension: The use–engagement–access model: *UEnAc.*

These nodes of tension seem to correspond with the three major groups of people trying to establish a stake in this specialist field. The central field can be represented in a triangle that resembles the phase diagrams used by chemists, geologists, mathematicians and physicists (see Figure 2). Readers will recall that effective models synthesise current knowledge, distinguish between things that might otherwise remain blurred and suggest directions for future work.

We have been discussing how the use of 'literacy' has been expanding over a considerable period of time and how the word has been used in various ways within Science. This model may seem a plausible inference from reflection on the literature discussed above but it remains merely conceptual without some sort of empirical challenge. Perhaps Science Education might provide data for such a challenge. The International Journal of Science Education (IJSE); Journal of Research in Science Teaching (JRST); Research in Science Education (RSE); Science Education (SE), and Studies in Science Education (SSE) are the most prestigious research journals within that field and ten years of publication within them was recently reviewed.

There are a number approaches to a broad review: ranging from automated content and citation counts, through multi-stage clustering techniques and sampling followed by close analysis, to content analysis of article abstracts. Our earlier work sought to "extend that existing work by exposing the

areas of greatest concentration in broadly contemporary science education research, illuminating the areas with potential for further work and identifying those parts of the field that may be diminishing in importance" through content analysis of the abstracts of 2294 articles from those five journals, published between 2005 and 2014. Restricting the analysis to article abstracts represents a conservative approach to such coding: an article was only associated with a particular category if its authors had considered that category important enough to mention in the abstract.

Four article types and five topics emerged together with multiple sub-categories. The article types were coded by Method (74.11% of abstracts providing identifiable description), Methodology (56.19%), Level (50.17%) and Discipline (42.33% of abstracts specifying science discipline). The major topics that emerged were Scientific Literacy (51.92% of abstracts mentioning the topic), Teaching (45.12%), Learning (42.33%), Teachers (36%) and Relations between Science and Education (16.17% of abstracts indicating focus on the topic).

The ten year survey used a coding sheet that comprised a series of short paragraphs describing each type or topic and providing spaces for inserting relevant articles as in-text references. This is described in more detail below. Reviewers entered references into more than one coding category if abstract content suggested it. The validity of this review process was supported by the broad agreement of its results with previous work and with the later, more restricted review of one of its focus journals [82].

Scientific Literacy emerged as the most frequent topic within those journals (1191 mentions: topic coded in over 50% of abstracts). The topic was separated into a number of non-exclusive sub-categories, all of which were found described as 'science/scientific literacy' in the literature. The publication frequency data for these sub-categories was analysed under the General Linear Model. SPSS provides four tests of multivariate significance, of which Pillai's trace is the most appropriate for small samples. In this case, all tests show statistically significant differences between journal publication rates for the 'Literacy' sub-categories (F = 7.018; df = 3.0, 7.0; Sig. = 0.016; $p < 0.05$). The assumption of sphericity was met (Mauchly's Test was not significant: W = 0.409, df = 5, Sig = 0.231, $p > 0.05$), and within subjects effects for the components of the category were statistically significant (df = 3; F = 7.459; Sig = 0.001; $p < 0.05$). This yielded an effect size (η^2) of 0.453, which is considered large ($\eta^2 > 0.138$), and an observed power of 0.970. These differences in publication patterns appear robust enough to permit discussion.

Our earlier work does not provide as broad a base of data as that dealing with canoe voyages during the Pacific expansion of the Polynesian peoples. However, the most frequent topic within a corpus of 2294 publications should provide sufficient data to determine whether the model can resolve details of that corpus sufficiently to identify both differences between journals and differences within journals across time.

Consequently, we re-analysed that portion of the wider data to reflect the distinctions between Use, Engagement and Access and compared publication rates within and between journals across the decade in question. If the model holds, we should be able to distinguish between journals and within journals over time. Readers should note, at this point, that we use this data to challenge the model we inferred from the literature, rather than to critique editorial decisions within any of the target journals.

7. An Empirical Challenge

The previous section has indicated the provenance of the *UEnAc* model that we are proposing and this section will apply it to International Journal of Science Education; Journal of Research in Science Teaching; Research in Science Education; Science Education, and Studies in Science Education. The information emerging may be useful in its own right and capacity to resolve differences in publication patterns in those journals would suggest that the *UEnAc* model might be effective.

The following version of the relevant section of the coding sheet, populated by more recent, exemplary references, more clearly illustrates the sub-categories that emerged as nodes of tension

within Scientific Literacy. The italics in the paragraphs below reflect those in the original coding sheets and were intended to aid in consistency between coders over the length of the process.

Access is the fundamental sense of '*literacy*': both *spoken* [83] and *written* [84] *communication*; dealing with use of *authentic literature* [85], *diagrams* [86], the impact of *bilingualism* [87], *argumentation* [88] and *explanation* [89] or *numeracy* issues in science learning [90].

Use rests on the derived use of '*literacy*'. What do people need to know to be '*truly literate*' in science [91] and where are schools *succeeding* (and/or failing) in helping them to become so [92]?

Engagement specifically recognizes the impact of *different learners* [93], or *families* [94], or *teachers* [95], or *cultures* [96] on science learning.

Counting the number of in-text references associated with each component of the subcategory yielded totals such as those appearing on Tables 1 and 2. If the examples above had represented one of the journals, during one of the 5-year spans, Access would yield a count of 8; Use a count of 2 and Engagement would yield a count of 4.

Table 1. Counts of Science Literacy across all five science education research journals.

Sub-Category	2005–2009 *n* = 955 *	R [@]	2010–2014 *n* = 1339 *	R [@]
Use	172 (18.01%) [#]	2	212 (15.83%)	2
Engagement	112 (11.70%)	3	161 (12.00%)	3
Access	238 (24.90%)	1	296 (22.10%)	1
Total	522 (54.66%)		669 (49.96%)	

Notes: * Articles are double coded, that is the content of a single article may place it in more than one category; [#] 172 mentions coded as 'Use' represented 18.01% of the 955 abstracts analysed in these journals from 2005 to 2009; [@] Proportional Rank across journals within table.

Table 2. Comparison of journal patterns in Science Literacy publication.

Sub-Category	JRST [1] 2005–14	JRST 5–9	JRST 10–14	SE 5–14	SE 5–9	SE 10–14	RISE 5–14	RSE 5–9	RSE 10–14
Use [2]	*141* **34%**	*103* 43%	*38* 23%	*49* **22%**	*19* 17%	*30* 27%	*60* **36%**	*15* 27%	*45* 40%
Engagement [2]	*144* **35%**	*85* 35%	*59* 35%	*47* **21%**	*22* 20%	*25* 23%	*14* **8%**	*0* 0	*14* 13%
Access [2]	*125* **30%**	*54* 22%	*71* 42%	*123* **56%**	*68* 62%	*55* 50%	*93* **56%**	*40* 73%	*53* 47%
Total	**410**	242	168	**219**	109	110	**167**	55	112
Sub-Category	SSE 5–14	SSE 5–9	SSE 10–14	IJSE 5–14	IJSE 5–9	IJSE 10–14	Total *No. %*		
Use [2]	*6* **26%**	*2* 50%	*4* 21%	*128* **34%**	*33* 29%	*95* 37%	*384* **32%**		
Engagement [2]	*5* **22%**	*0* 0	*5* 26%	*63* **17%**	*5* 4%	*58* 22%	*273* **23%**		
Access [2]	*12* **52%**	*2* 50%	*10* 53%	*181* **49%**	*74* 66%	*107* 41%	*534* **45%**		
Total	**23**	4	19	**372**	112	260	**1191**		

Notes: [1] *Journal abbreviations*: **JRST** (Journal of Research in Science Teaching); **SE** (Science Education); **RSE** (Research in Science Education); **SSE** (Studies in Science Education); **IJSE** (International Journal of Science Education); [2] *Row %*: Percentage of publications from category within time period represented by the column.

Table 1 provides the overall context for subsequent discussion by providing the coding numbers across all five research journals in each of the five-year spans described in the broader review. The percentage figures (%) in the columns on Table 1 result from division of the number of abstracts coded into a category by the total number of articles coded, with the resulting decimal multiplied by 100, so that the 172 abstracts containing some reference to the Use sense of science literacy, which were published in any of the five journals between 2005 and 2009, yielded a percentage of 18.01 when divided by 955, being the total number of papers published by all five journals between 2005 and 2009.

Effective conceptual models synthesise current knowledge and resolve differences between apparently similar areas of emerging knowledge. One effective way of challenging a model that emerges from a broad survey such as this is to apply it to a more restricted field and decide whether it exposes interactions that might otherwise remain obscure. Table 2 sets out the publication pattern in individual journals derived from the broad survey of these journals between 2005 and 2014. This represents the raw data for the empirical challenge that we are mounting to the Use–Engagement–Access model.

The data in the rows of Table 2 provide both number (in *italics*) and percentage (in **bold**) of publications within the particular sub-category (from the number coded within the literacy category) within the time period represented by the columns of journal data. Table 2 will be used to provide the data for the illuminative graphical representations of the the the *UEnAc* model that follow in Figures 3–5. Consequently, to avoid the error of misplaced precision, the proportional publication rates are presented as whole number percentages. For example, the 125 publications categorised as dealing with Access represented 30% of the 410 abstracts of articles from the Journal of Research into Science Teaching (JRST) categorised as dealing with Scientific Literacy from 2005 to 2014, inclusive. The varying numbers of articles published by journals at different times make such proportions more illuminative of trends than the abstract counts from which these percentages were derived.
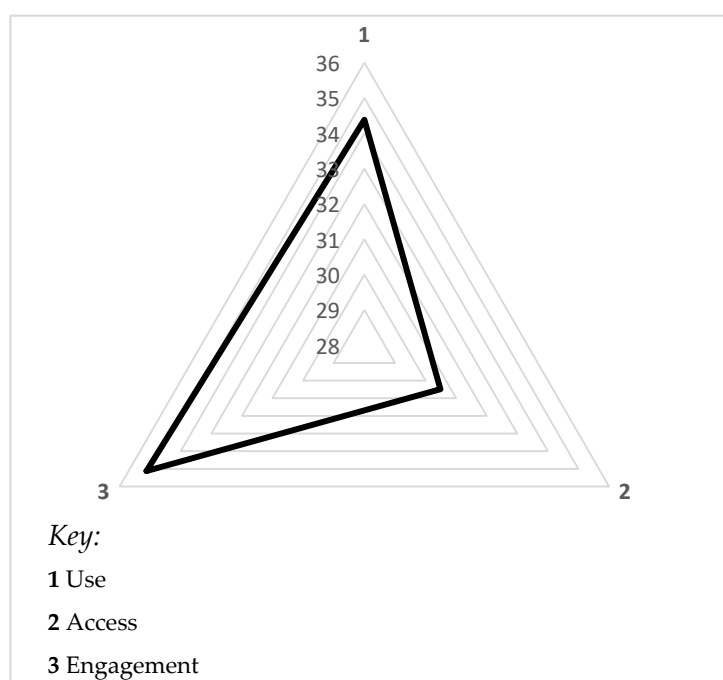

Key:

1 Use

2 Access

3 Engagement

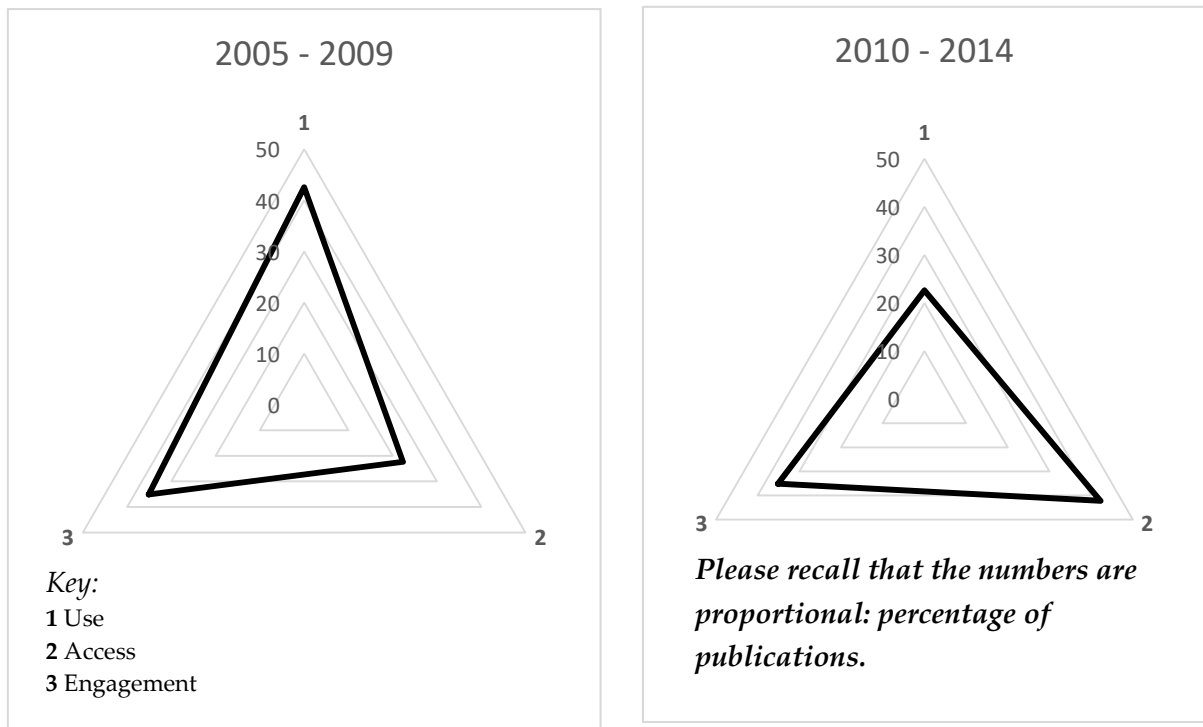**Figure 3.** Shape of literacy in JRST 2005-2014.

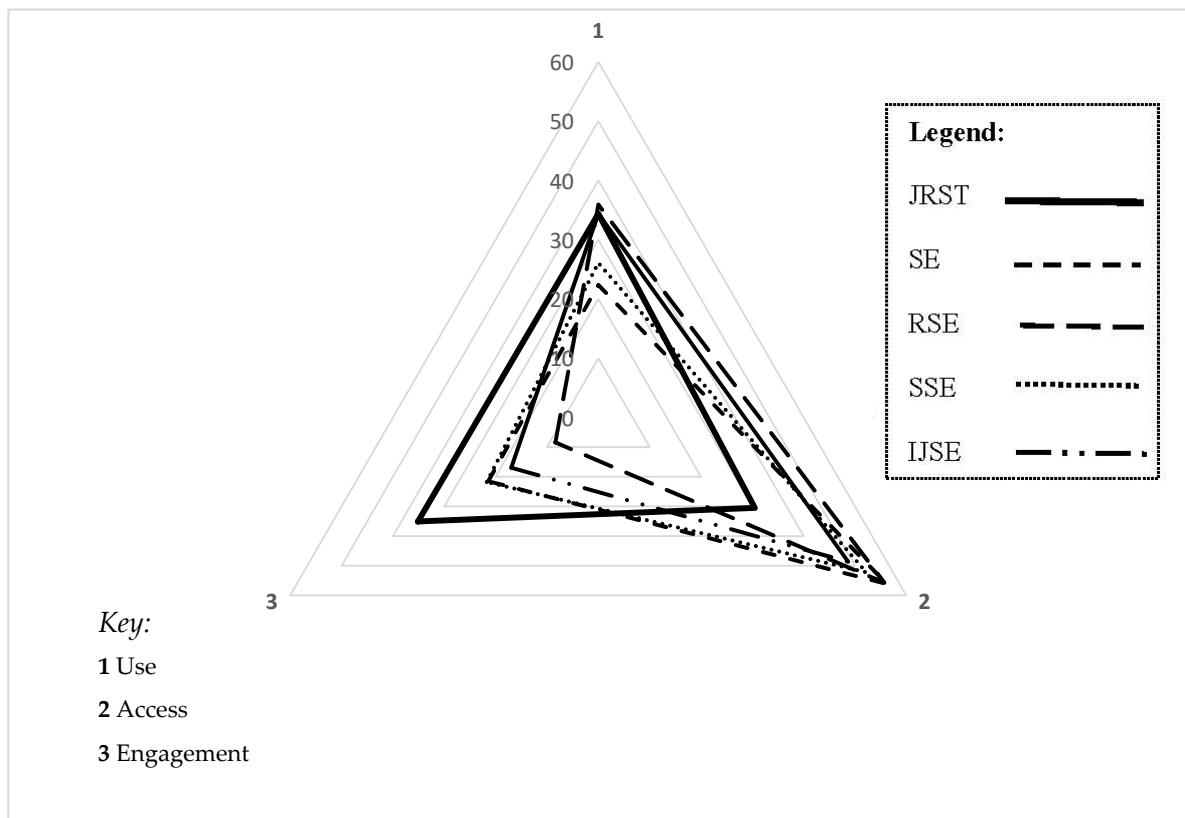**Figure 4.** Changing shape of Literacy in JRST 2005-2014.

Figure 5. Changing shape of Literacy across five Science Education journals.

These tabulated data are difficult to rapidly interpret. The trends are more obvious if the data for the ten years and the constituent five-year spans are separately mapped onto the *UEnAc* model.

Figure 3 suggests that articles dealing with the 'Use' and 'Engagement' senses of Scientific Literacy were more common in the Journal of Research in Science Teaching (JRST) between 2005 and 2014.

However, separation of the five-year spans on Figure 4 suggests that the proportion of published articles dealing with the fundamental Access aspect rose between the first half of the ten years in question and the second. There was an apparent shift in researcher or editorial focus, or there was a shift in both.

The model also reveals differences between the patterns of publication between the five journals. Figure 5 contains the *UEnAc* models for all five journals and it suggests that JRST was slower to take up the increasing interest in Access evident in the other journals, across the years in question. The other journals had a lower proportion of publication of articles dealing with the Engagement aspect. Research in Science Education (RSE) seems to have been proportionally less interested in the socio-cultural and socio-scientific issues that might engage students through access to museums and science journalism than the other journals. RSE and JRST seem to have published proportionally equivalent amounts of research into the 'Use' of science during this decade, perhaps suggesting similar editorial interest in the tensions between 'science for all' and 'science for the specialist' that characterise this apex of the model.

Such use of the model prompts additional questions:

1. How does the change in JRST pattern compare to that in the International Journal of Science Education (SE: the other larger journal)?
2. Does the change represent publication lag or editorial policy?
3. Is there a jurisdiction effect?
4. Has the apparent contrast between JRST and RSE persisted since 2014?
5. Do the trends apparent across Figures 3–5 represent jurisdictional policy shifts, funding sources, researcher interest, editorial focus or some mixture of these?

The emergence of such questions subsequent to application of the model supports its usefulness.

8. So What Is 'Discipline Literacy'?

Lack of recognition of the multiple meanings of the core word lies beneath much of the muddiness of discussions about 'literacy'. The model presented in this paper may clarify tensions between the purposes for which various groups of people use the word and prompt questions as to what constitutes ideal specialist education, or of how people should strive for specialist literacy.

The term scientific literacy has come to have "so many interpretations that it now means virtually everything to do with science education" [97]. That comment was made a generation ago and other subject literacies may well be prone to the same diffusion of meaning. However, should we look for congruence between the shapes of the patterns of proportional publication in the various journals? If 'literacy' is *engagement*, *access* and *use*, do all attempts to encourage literacy among students necessarily involve all three aspects? Perhaps literacy is one area where balance may not be appropriate. Different audiences have legitimate needs for different interactions of access, engagement and use. However, choice of appropriate response is more likely if negotiating parties are clear about what they are discussing.

All of those promoting scientific literacy hope that young people will want to know more about science. We want them to be able to understand us and to be able to show that they do. We want young people to understand our specialty and why it is important, and also we want them to be able to evaluate the quality of specialist work. We are not naive idealists—we know that all of this happens at different levels for different age groups and that some people have more trouble than others. However, not everybody involved in science necessarily shares all of this comprehensive agenda.

Primary school teachers who are beginning to introduce science to their classes may be more interested in Engagement and Access, the bottom of the Figure 2 triangle: "How am I going to engage

my class, help them to understand me and move them towards greater understanding?" Their concerns will probably move up from the baseline as their classes become more experienced with science.

University lecturers may assume that their students already have access and are already sufficiently engaged and so may put most of their energy into the top apex of the triangle. Generally speaking, people involved in museums, zoos and science centers focus on Engagement and people involved in industry and higher education focus on Use. However, lack of access can kill engagement and make use impossible.

9. Potential and Limitations of an Initially Successful Model

The *UEnAc* model emerged from reflection on 'literacy' in a particular disciplinary area but it is an area where tensions in the way the word is used have been evident for quite some time. The literature base emerging from those tensions provided a fruitful resource for model development. Modelling scientific literacy as the interaction of Use, Engagement and Access exposed differences in publication patterns between journals and across time within at least one of them. The model has survived the initial challenge presented to it and posed a number of subsequent questions that may not have appeared without it.

The model that emerged is a reflective tool that is potentially useful for anyone working in any aspect of specialist literacy, especially those working across several different aspects. Users can map individual pieces of published work onto the model to reflect the focus of its author, as revealed by its reference list, or the emphasis of a review of publications or the preconceptions of a speaker. Different activities, and different people, fit at different points across the entire area of the triangle, although all are likely to describe what they do as 'communication', 'literacy' or 'education'. Only those located right at an apex can safely ignore the rest of the model.

This might be a useful process for those attempting to contribute to the field. The pattern of work read could reveal gaps or obsessions. What are the themes expressed in the abstract of the paper? How often do those themes emerge in the work as a whole? What is the proportion of one theme as compared to another? Document analysis packages can quantify the answers to such questions, if such precision is required or desired.

Our *UEnAc* model suggests that all three aspects of ***Access to***, ***Engagement with*** and ***Use of*** specialist knowledge are contextually legitimate and useful senses of discipline literacy in the cases we have explored. Further, the distinction between them may be fruitful further afield. Some people discussing Economic Literacy, for example, may be more interested in how well the general public understands economic issues at election time than they are in how often a particular demographic group reads the Business section of metropolitan newspapers or how much they understand of what they read when they do. All of these concerns fall under the heading of Economic Literacy but issue resolution is more difficult if advocates suggest effective ways of encouraging people to read the Business section (Engagement) as responses to problems that emerge when they try to read it (Access).

The insights gained by use of the *UEnAc* model lead us to suggest that the three senses of Discipline Literacy that we have elucidated seem to be distinct but mutually reinforcing. Literacy involves engagement with the discipline, which will require some access to disciplinary work before use of the products of that work. Engagement is essential but no use is possible without access. The kind of use intended will determine the degree of access required.

The major limitation of this work is its basis in analysis of publication patterns in a restricted range of journals in a period of time that is fast receding. These results rest on data from five journals but that data ended in 2014. It served as a defensible base for the empirical challenge of a model emerging from wider literature, but its usefulness for contemporary editors of those journals is limited. As mentioned earlier in this paper, the point was not critique of data sources but challenge of a model. The Use, Engagement, Access model of science literacy seems to have survived that challenge. Further work could quantify its usefulness within other disciplinary areas and clarify the extent of its usefulness

within contemporary controversies muddied by the constituents and interactions of the substantial bases of words used for the weight of their impact.

References

1. Turnbull, P. ASTA Response to the National Curriculum Board Science Framing Paper. 23 February 2009. Available online: http://www.asta.edu.au/freestyler/files/ASTA%20response%20to%20the%20national%20curriculum%20board%20final.doc (accessed on 5 July 2009).

2. Norris, S.P.; Phillips, L.M. How literacy in its fundamental sense is central to scientific literacy. *Sci. Educ.* **2003**, *87*, 224–240. [CrossRef]

3. Spires, H.; Kerkhoff, S.N.; Graham, A.C.K.; Thompson, I.; Lee, J.K. Operationalizing and validating disciplinary literacy in secondary education. *Read. Writ.* **2018**, *31*, 1401–1434. [CrossRef] [PubMed]

4. Freebody, P.; Luke, A. Literacy as engaging with new forms of life: The four roles model. In *The Literacy Lexicon*, 2nd ed.; Anstey, G.B.M., Ed.; Pearson: Sydney, Australia, 2002; pp. 51–65.

5. Gee, J.P. *What Video Games have to Teach Us about Learning and Literacy*; Palgrave Macmillan: New York, NY, USA, 2003.

6. Lachuk, A.J. The socio-historical mandate for Literacy and Education in the Rural South: A narrative perspective. *Res. Teach. Engl.* **2015**, *50*, 84–110.

7. Gould, S.J.; Marshall, S.; Scheppler, J.A.; Palmisano, M.J. *Science Literacy for the Twenty-First Century*; Prometheus Books: Amherst, NY, USA, 2003.

8. Granville, S.; Laura, D. Thinking about thinking: Integrating self-reflection into an academic literacy course. *J. Engl. Acad. Purp.* **2005**, *4*, 99–118. [CrossRef]

9. Knain, E. Identity and genre literacy in high-school students' experimental reports. *Int. J. Sci. Educ.* **2005**, *27*, 607–624. [CrossRef]

10. Ross, K.M.; Joseph, L.M. Effects of word boxes on improving students' basic literacy skills: A literature review. *Prev. Sch. Fail. Altern. Educ. Child. Youth* **2018**, *63*, 43–51. [CrossRef]

11. Semali, L. *Literacy in Multimedia America: Integrating Media Education across the Curriculum*; Falmer Press: New York, NY, USA, 2000.

12. Roser, M.; Ortiz-Ospina, E. Literacy. Our World in Data. 2018. Available online: https://ourworldindata.org/literacy (accessed on 15 August 2019).

13. Pantaleo, S. Language, literacy and visual texts. *Engl. Educ.* **2015**, *49*, 113–129. [CrossRef]

14. Barton, G. The arts and literacy: What does it mean to be arts literate? *Int. J. Educ. Arts* **2013**, *14*. Available online: http://www.ijea.org/v14n18/ (accessed on 15 August 2019).

15. Gordon, J. Reading from nowhere: Assessed literary response, practical criticism and situated cultural literacy. *Engl. Educ.* **2018**, *52*, 20–35. [CrossRef]

16. Neitzel, S.M.; van Zwieten, P.A.M.; Hendriksen, A.; Duggan, D.; Bush, S.R. Returning information back to fishers: Graphical and numerical literacy of small-scale Indonesian tuna fishers. *Fish. Res.* **2017**, *196*, 96–105. [CrossRef]

17. Seemann, K.; Talbot, R. Technacy: Towards a holistic understanding of technology teaching and learning among Aboriginal Australians. *Prospects* **1995**, *25*, 761–775. [CrossRef]

18. Gerrans, P.; Heaney, R. The impact of undergraduate personal finance education on individual financial literacy, attitudes and intentions. *Account. Financ.* **2019**, *59*, 177–217. [CrossRef]

19. Shanahan, T.; Shanahan, C. Teaching disciplinary literacy to adolescents: Rethinking content-area literacy. *Harv. Educ. Rev.* **2008**, *78*, 40–59. [CrossRef]

20.	NGA/CCSSO. Common Core State Standards for English language Arts & Literacy in History/Social Studies, Science, and Technical Subjects. 2010. Available online: http://www.corestandards.org/assets/CCSSI_ELA%20Standards.pdf (accessed on 15 August 2019).

21.	Shanahan, T.; Shanahan, C. What Is Disciplinary Literacy and Why Does It Matter? *Top. Lang. Disord.* **2012**, *32*, 7–18. [CrossRef]

22.	Anstey, M.; Bull, G. *The Literacy Labyrinth*, 1st ed.; Prentice Hall: Sydney, Australia, 1996.

23.	Samarapungavan, A.; Westby, E.L.; Bodner, G.M. Contextual epistemic development in science: A comparison of chemistry students and research chemists. *Sci. Educ.* **2006**, *90*, 468–495. [CrossRef]

24.	Wade-Jaimes, K.; Demir, K.; Qureshi, A. Modeling strategies enhanced by metacognitive tools in high school physics to support student conceptual trajectories and understanding of electricity. *Sci. Educ.* **2018**, *102*, 711–743. [CrossRef]

25.	Thompson, C. *Sea People: The Puzzle of Polynesia*; William Collins: London, UK, 2019.

26.	Levison, M.; Ward, R.G.; Webb, J.W. *The Settlement of Polynesia: A Computer Simulation*; University of Minnesota Press: Minneapolis, MN, USA, 1973.

27.	Becker, W.; Conroy, S.; Djurdjevic, E.; Goss, M. Crying is in the eye of the beholder: An attribution theory framework of crying at work. *Emot. Rev.* **2018**, *10*, 125–137. [CrossRef]

28.	Pierson, A.E.; Clark, D.B. Engaging students in computational modeling: The role of an external audience in shaping conceptual learning, model quality, and classroom discourse. *Sci. Educ.* **2018**, *102*, 1336–1362. [CrossRef]

29.	Wilkerson-Jerde, M.; Wagh, A.; Wilensky, U. Balancing curricular and pedagogical needs in computational construction kits: Lessons from the Delta Tick Project. *Sci. Educ.* **2015**, *99*, 465–499. [CrossRef]

30.	Shim, S.-Y.; Kim, H.-B. Framing negotiation: Dynamics of epistemological and positional framing in small groups during scientific modeling. *Sci. Educ.* **2017**, *102*, 128–152. [CrossRef]

31.	Schuchardt, A.M.; Schunn, C.D. Modeling scientific processes with mathematics equations enhances student qualitative conceptual understanding and quantitative problem solving. *Sci. Educ.* **2016**, *100*, 290–320. [CrossRef]

32.	Ellis, N.C. Cognition, corpora and computing: Triangulating research in usage-based language learning. *J. Res. Lang. Stud.* **2017**, *67*, 40–65. [CrossRef]

33.	O'Toole, J.M.; Freestone, M.; McKoy, K.; Duckworth, B. Types, topics and trends: A ten-year review of research journals in Science Education. *Educ. Sci.* **2018**, *8*, 73. [CrossRef]

34.	Layton, D.; Davey, A.; Jenkins, E.W. Science for specific social purposes (SSSP): Perspectives on adult literacy. *Stud. Sci. Educ.* **1986**, *13*, 27–52. [CrossRef]

35.	Zen, E. Scientific literacy: What is it, why is it important and what can scientists do to improve the situation? *Aust. Sci. Teach. J.* **1992**, *38*, 18–23.

36.	Lively, B.A.; Pressey, S.L. A method for measuring the 'vocabulary burden' of textbooks. *Educ. Adm. Superv.* **1923**, *9*, 389–398.

37.	Cleland, B.; Evans, R. *Learning English through general science*; Longman Cheshire: Melbourne, Australia, 1984.

38.	Swales, J.M. *Writing Scientific English*; Nelson: London, UK, 1971.

39.	Kennedy, A. *Whatever the Weather, a Course Set for Terror*; Sydney Morning Herald: Sydney, Australia, 2000; p. 1.

40.	Walker, D. *There are no Votes in Poor Site Design*; Sydney Morning Herald; Tech Economy: Sydney, Australia, 21 November 2000; p. 5.

41.	Cambourne, B. *The Whole Story: Natural Learning and the Acquisition of Literacy*; Ashton Scholastic: Auckland, New Zealand, 1988.

42.	Halliday, M.A.K. *An Introduction to Functional Grammar*, 2nd ed.; Edward Arnold: London, UK, 1994.

43.	Cope, B.; Kalantzis, M. (Eds.) *Multiliteracies: Literacy Learning and the Design of Social Futures*; Routledge: London, UK, 2000.

44.	Smagorinsky, P. Disciplinary Literacy in English Language Arts. *J. Adolesc. Adult Lit.* **2015**, *59*, 141–146. [CrossRef]

45.	Laugksch, R.C. Scientific literacy: A conceptual overview. *Sci. Educ.* **2000**, *84*, 71–94. [CrossRef]

46.	Prain, V.; Waldrip, B. Representing science literacies: An introduction. *Res. Sci. Educ.* **2010**, *40*, 1–3. [CrossRef]

47.	Bodmer, W. Scientific literacy for health and prosperity. *Sch. Sci. Rev.* **1989**, *70*, 9–20.

48. Lucas, A. Scientific literacy and informal learning. *Stud. Sci. Educ.* **1983**, *10*, 1–36. [CrossRef]

49. Shamos, M.H. Science literacy is futile: Try science appreciation. *Scientist* **1988**, *9*, 12.

50. Thomas, G.; Durant, J. Why should we promote the public understanding of science? In *Scientific Literacy Papers*; Shortland, M., Ed.; Oxford Department of External Studies: Oxford, UK, 1987; pp. 1–14.

51. AAAS. *Benchmarks for Science Literacy*; Oxford University Press: New York, NY, USA, 1993.

52. Thomson, S.; DeBortoli, L. *Exploring Scientific Literacy: How Australia Measures Up: The PISA 2006 Survey of Students Scientific, Reading and Mathematical Literacy Skills*; ACER Press: Camberwell, Australia, 2008.

53. Alexander, J.; Walsh, P.; Jarman, R.; McClune, B. From rhetoric to reality: Advancing literacy by cross-curricular means. *Curric. J.* **2008**, *19*, 23–35. [CrossRef]

54. Barton, M.L.; Jordan, D.L. *Teaching Reading in Science: A Supplement to 'Teaching Reading in the Content Areas, Teacher's Manual'*, 2nd ed.; McRel: Aurora, CO, USA, 2001.

55. Mackay, R.; Mountford, A. (Eds.) *English for Specific Purposes: A Case Study Approach*; Longman: London, UK, 1978.

56. Master, P.A.; Brinton, D. *New Ways in English for Specific Purposes*; Teachers of English to Speakers of Other Languages Inc: Alexandria, VA, USA, 1998.

57. Robinson, P.C. *ESP (English for Specific Purposes): The Present Position*, 1st ed.; Pergamon Press: Oxford, New York, NY, USA, 1980.

58. Robinson, P.C. *ESP Today: A Practitioner's Guide*; Prentice Hall: New York, NY, USA, 1991.

59. Swales, J.M. *Episodes in ESP: A Source and Reference Book on the Development of English for Science and Technology*; Pergamon Press: Oxford, UK, 1985.

60. Afros, E.; Schryer, C.F. The genre of syllabus in higher education. *J. Engl. Acad. Purp.* **2009**, *8*, 224–233. [CrossRef]

61. August, D.; Hakuta, K. (Eds.) *Educating Language-Minority Children*; National Academy Press: Washington, DC, USA, 1998.

62. Clegg, J. *Mainstreaming ESL: Case Studies in Integrating ESL Students into the Mainstream Curriculum*; Multilingual Matters: Clevedon, UK; Philadelphia, PA, USA, 1996.

63. O'Toole, J.M. Climbing the fence around science ideas. *Aust. Sci. Teach. J.* **1998**, *44*, 51–56.

64. Yore, L.D.; Florence, M.K.; Pearson, T.W.; Weaver, A.J. Written discourse in scientific communities: A conversation with two scientists about their views of science, use of language, role of writing in doing science, and compatibility between their epistemic views and language. *Int. J. Sci. Educ.* **2006**, *28*, 109–141. [CrossRef]

65. Eckersley, R. The Skeptical Environmentalist: A sociocultural perspective. *Glob. Chang. Hum. Health* **2002**, *3*, 55–57. [CrossRef]

66. Fensham, P.J. Science for all. *Educ. Leadersh.* **1986**, *44*, 18–25.

67. Asención-Delany, Y. Investigating the reading-to-write construct. *J. Engl. Acad. Purp.* **2008**, *7*, 140–150. [CrossRef]

68. Gee, J.P. Opportunity to Learn: A language-based perspective on assessment. *Assess. Educ. Princ. Policy Pr.* **2003**, *10*, 27–46. [CrossRef]

69. Wallace, C.S.; Hand, B.; Prain, V. *Writing and Learning in the Science Classroom*; Kluwer Academic Publishers: Dordrecht, The Netherlands, 2004; Volume 23.

70. McClune, B.; Jarman, R. Critical reading of science-based news reports: Establishing a knowledge, skills and attitudes framework. *Int. J. Sci. Educ.* **2010**, *32*, 727–752. [CrossRef]

71. Sellah, A. Science in the media: The good the bad and the ugly. *Aust. Sci. Teach. J.* **2001**, *47*, 28–37.

72. Braund, M.; Reiss, M. Towards a more authentic science curriculum: The contribution of out-of-school learning. *Int. J. Sci. Educ.* **2006**, *28*, 1373–1388. [CrossRef]

73. Melber, L.M.; Abraham, L.M. Science education in U.S. natural history museums: A historical perspective. *Sci. Educ.* **2002**, *11*, 45–54. [CrossRef]

74. Parkinson, J.; Adendorff, R. The use of popular science articles in teaching scientific literacy. *Engl. Specif. Purp.* **2004**, *23*, 379–396. [CrossRef]

75. Fang, Z. The language demands of science reading in middle school. *Int. J. Sci. Educ.* **2006**, *28*, 491–520. [CrossRef]

76. Wassersug, R. Science as entertainment and entertainment science. *Informal Learn. Rev.* **2002**. Available online: http://www.informallearning.com/archive/Wassersug%2052.htm (accessed on 7 July 2010).

77. Murcia, K. Science for the 21st century: Teaching for scientific literacy in the primary classroom. *Teach. Sci.* **2007**, *53*, 16–19.

78. Roberts, P. Defining literacy: Paradise, nightmare or red herring? *Br. J. Educ. Stud.* **1995**, *43*, 412–432. [CrossRef]

79. Stern, F.; Kampourakis, K. Teaching for genetics literacy in the post-genomic era. *Stud. Sci. Educ.* **2017**, *53*, 193–225. [CrossRef]

80. Mujtaba, T.; Lawrence, M.; Oliver, M.; Reiss, M.J. Learning and engagement through natural history museums. *Stud. Sci. Educ.* **2018**, *54*, 41–67. [CrossRef]

81. Kulgemeyer, C. Towards a framework for effective instructional explanations in science teaching. *Stud. Sci. Educ.* **2019**, *54*, 109–139. [CrossRef]

82. Skamp, K. Research in Science Education (RISE): A Review (and Story) of Research in RISE Articles (1994–2018). *Res. Sci. Educ.* **2020**, 1–33. [CrossRef]

83. Bungum, B.; Bøe, M.V.; Henriksen, E.K. Quantum talk: How small-group discussions may enhance students' understanding in quantum physics. *Sci. Educ.* **2018**, *102*, 856–877. [CrossRef]

84. Bjørkvold, T.; Blikstad-Balas, M. Students as researchers: What and why seventh-grade students choose to write when investigating their own research question. *Sci. Educ.* **2018**, *102*, 304–341. [CrossRef] [PubMed]

85. Shea, N.A. Examining the nexus of science communication and science education: A content analysis of genetics news articles. *J. Res. Sci. Teach.* **2015**, *52*, 397–409. [CrossRef]

86. Aberg-Bengtsson, L.; Karlsson, K.G.; Ottosson, T. 'Can there be a full moon at daytime?' Young students making sense of illustrations of the lunar phases. *Sci. Educ.* **2017**, *101*, 616–638. [CrossRef]

87. Wilmes, S.E.D.; Siry, C. Interaction rituals and inquiry-based science instruction: Analysis of student participation in small-group investigations in multilingual classroom. *Sci. Educ.* **2018**, *102*, 1107–1128. [CrossRef]

88. Erduran, S.; Ozdem, Y.; Park, J.-Y. Research trends on argumentation in science education: A journal content analysis from 1998–2014. *Int. J. STEM Educ.* **2015**, *2*, 12. [CrossRef]

89. Papadouris, N.; Vokos, S.; Constantinou, C.P. The pursuit of a 'better' explanation as an organizing framework for science teaching and learning. *Sci. Educ.* **2018**, *102*, 219–237. [CrossRef]

90. Chesnutt, K.; Jones, M.G.; Corin, E.N.; Hite, R.; Childers, G.; Perez, M.P.; Ennes, M. Crosscutting concepts and achievement: Is a sense of size and scale related to achievement in science and mathematics? *J. Res. Sci. Teach.* **2018**, *56*, 302–321. [CrossRef]

91. Sharma, A.; Buxton, C.A. Human–Nature relationships in school science: A Critical Discourse Analysis of a middle-grade science textbook. *Sci. Educ.* **2015**, *99*, 260–281. [CrossRef]

92. Kapon, S.; Laherto, A.; Levrini, O. Disciplinary authenticity and personal relevance in school science. *Sci. Educ.* **2018**, *102*, 1077–1106. [CrossRef]

93. Katsch-Singer, R.; McNeill, K.L.; Loper, S. Scientific argumentation for all? Comparing teacher beliefs about argumentation in high, mid, and low socioeconomic status schools. *Sci. Educ.* **2016**, *100*, 410–436. [CrossRef]

94. Tscholl, M.; Lindgren, R. Designing for learning conversations: How parents support children's science learning within an immersive simulation. *Sci. Educ.* **2016**, *100*, 877–902. [CrossRef]

95. Tang, K.-S. Analyzing teachers' use of meta-discourse: The missing element in classroom discourse analysis. *Sci. Educ.* **2017**, *101*, 548–583. [CrossRef]

96. Meyer, X.S.; Crawford, B.A. Multicultural inquiry toward demystifying scientific culture and learning science. *Sci. Educ.* **2015**, *99*, 617–637. [CrossRef]

97. Roberts, D.A. *Scientific Literacy. Towards Balance in Setting Goals for School Science Programs*; Science Council of Canada: Ottawa, ON, Canada, 1983.