SCIENTIFIC LITERACY: A MULTI-DISCIPLINARY EXPLICATION AND EMPIRICAL STUDY OF THE CONCEPTIONS OF SCIENCE GRADUATE STUDENTS

BY

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THESIS

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ABSTRACT

In the literature there are myriad definitions and conceptions of what it means to be scientifically literate (SL), resulting in an amalgam of prescriptions, aims, objectives, and learning goals all falling under the same umbrella term. What is missing is a systematic explication of this complex concept, stemming from its two constituent parts: science and literacy. Chapter one examines the natural intersections between science and literacy to build a theoretical typology of the components that define SL. Chapter two utilizes this typology to analyze the definitions individuals use in practice, or their practical definitions of SL, to understand the relationship between how SL is conceptualized in theory versus in practice. This analysis focuses on graduate students in the sciences and in science education, as these individuals are in a position to impact public understanding of science through both formal and informal educational settings, as well as dissemination of scientific information through broader impacts and outreach. Nine total participants responded to an open-ended web-based survey asking them to define science, literacy, and SL both explicitly and implicitly. These results are compared to the theoretical typology as well as all relevant literature that elicits individuals' definitions of scientific literacy. Consistent with the prior literature, there is a large focus on the content of science, but only as it can be applied to one's life. While there are many similarities between theoretical and practical definitions of SL there are also large, holistic differences between the two. For science graduate students, practical definitions of SL have a much greater focus on the scientific enterprise, with less of a focus on literacy or the intersection with other domains. This is much less balanced than the theoretical definitions in the literature. Further, the number and type of components included in practical definitions of SL vary widely by individual. This could have large implications for what is communicated to the public about science, and what is emphasized in educational settings; conflicting messages about what science is or entails could have large impacts on public understanding of science.

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CHAPTER 1 – A MULTI-DISCIPLINARY EXPLICATION OF SCIENTIFIC LITERACY

In the literature, one can find almost endless ideas regarding what it means to be scientifically literate, ranging from lip service in an empirical study to a book dedicated to the topic. It is crucial to articulate the landscape of ideas regarding scientific literacy to understand the impacts this has on public understanding of science, as these myriad conceptions may lead to conflicting messages for the public about science. For example, Roberts (2011) theorizes that within the formal educational sphere there are two competing visions of the purpose of science, either focusing on the scientific enterprise itself (vision 1) or the application to human affairs (vision 2), and this results in conflicting resources for educators, and different long-term outcomes for students, all stemming from the same broad term *scientific literacy*[1]. This would mean that, depending on which vision an educator subscribed to, students would have a drastically different understanding of what science entails. I will argue that there are many such "visions" of scientific literacy, or several different components that all fall under this same umbrella term. These are often applied in different areas and contexts without defining the differences between them, or researching the potential impact of doing so.

> Beneath a superficial consensus, [scientific literacy] reveals itself to be a rather polysemic expression. Extensive research and practice on [scientific literacy] has indicated that it can be conceptualized, among other alternatives, as a teaching objective, as a learning goal, as a framework for curriculum development, as a basis to assess public understanding of science, and as a research topic...either as an individual attribute or as something that is distributed within social systems...within the fields of citizenship education and multicultural education. (Martins, 2011, p. 91)

How one explicates scientific literacy (SL), or which of the many competing definitions one chooses, will result in very different outcomes with regards to the interface between science educators and the general public. These educators are not always in a formal educational setting; though this is likely the most impactful subset, they can also be scientists and engineers executing broader impacts (which are expanded on later) and outreach programs in informal or formal settings, or those in the public health fields (large scale organizations, doctors, epidemiologists, etc.) that disseminate information related to the health and wellbeing

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[1] Both *science literacy* and *scientific literacy* are used interchangeably in the literature (Snow & Dibner, 2016), so the choice to use scientific literacy throughout this document was arbitrary

of their citizens. How each of these subsets of individuals, and the individuals within these fields, understand and execute their understanding of SL will greatly impact the messages the public receives about science. These messages, and their implications, must be understood before we can address any potential gaps in SL among the public. Otherwise, assessments of the extent to which the public is "literate" cannot be contextualized with a single definition, or framed within its components, resulting in such extreme statements as the following by Maienschein with students (1998) in *Science*, "by the broadest definition, more than 90% of Americans are scientifically illiterate—an appalling statistic by anyone's standards and possibly a threat to our well-being" (p. 917) or from the American Association for the Advancement of Science (AAAS), "most Americans are not science-literate" (AAAS, 1990, p. *xv*).

Assessments to the extent (or lack) of public SL must come after a consensus of *what* SL exactly entails. Therefore, the first step towards understanding, and ultimately bolstering, public SL is to explicate this broad and complex concept: to explicitly define the term, using the current landscape of implicit and explicit definitions, to remove any ambiguity about what SL is or how it should be applied. While the field is highly populated with ideas regarding SL, we are far from a comprehensive or established definition for SL, or even a decision as to which domain(s) it should apply. Further, these myriad definitions are constructed without explicit reference to their two components: science and literacy. While it is possible that scientific literacy is only tangentially related to its components, *science* and *literacy,* given the focus on how well an individual understands *science*, and that this is typically measured through one's ability to convey this information through reading, writing, or speech, it seems more likely that these two components are central to the definition of SL. Therefore, understanding how all of these many definitions relate to one another, and how they relate to both science and literacy, is a crucial step towards elucidating how these different conceptions of SL could impact public understanding of science. This paper will explore each of the components of SL, and the connections between them, to understand fully what SL might entail. Definitions of SL across several disciplines will be examined and compared to determine if there are disciplinary differences in the natural overlap between science, literacy, and SL. Finally, these definitions will be applied to create a comprehensive theoretical typology of scientific literacy.

The Literacy Component of Scientific Literacy

What is "Literacy"?

From the inception of the term, *literacy* has been intimately connected with reading and writing, and education as a means of becoming literate. The terms *literate* and *illiterate* have been in use since the early 15th century, meaning "educated, instructed"[2] and "uneducated, unable to read and write"[3], respectively. These terms both stem from Latin: *illiteratus*, meaning "unlearned, unlettered, ignorant; without culture, inelegant"[3]; *litteratus*, meaning "furnished with letters"[3], or "one who knows the letters"[2] (Illiterate (adj.), n.d.; Literate (adj.), n.d.). There has been a pervasive dichotomy in how literacy has been defined, as the ability to read and write as compared to learned or educated. While there has been a shift in how the term literate has been defined (Norris & Phillips, 2015) and measured (Bybee, 1997) over time, current definitions still have reading and writing as the central components. For example: "able to read and write; (also) of or relating to this ability. Opposed to *illiterate"* (Literate, adj. and n., 2016). It was only in the last century that the term literacy has been so bounded within the ability to read and write (Norris & Phillips, 2015). Many scholars would contest this bounded nature, citing the permeability of text with culture, context, and individual meaning-making. Both oral and written texts are infused with cultural meaning, the prose itself inseparable from the time, context, constraints, assumptions, subjectivities, and intentionalities of its creation. This meaning is dynamic, shifting and being shaped by each time, culture, context, and individual that engages with it. Engagement with text is never done in isolation from social context or cultural practices, and is never a neutral act (Street, 2001). This means that literacy defined by only reading and writing falls flat of the dynamic process of the creation, interpretation, and engagement with text. "Literacy involves more than just reading and writing texts, but rather entails actions, beliefs, values, social practices, and identity formation" (Kelly, 2011, p. 63). "Thus, what is important is not language, and surely not grammar, but *saying (writing)-doing-being-valuing-believing combinations*", or what Gee refers to as Discourses (Gee, 1989, p. 6).

For Gee, literacy is an amalgam of socially accepted ways of being, and a means to identify one's self as a member of a group, a mastery or control over "secondary Discourse".

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[2] From Literate (adj.) (n.d.)

[3] From Illiterate (adj.) (n.d.)

> Discourses are ways of being in the world; they are forms of life which integrate words, acts, values, beliefs, attitudes, and social identities as well as gestures, glances, body positions, and clothes…we all have many Discourses. (Gee, 1989, pp. 6-7)

There are Discourses that we are born into, and there are Discourses that we acquire through acculturation into their social practices. The latter are secondary Discourses, of which there are many. More broadly, discourse is "ways of using language in social contexts" (Kelly, 2011, p. 62). This relationship between Discourse and literacy means there are many possible literacies. These literacies are dynamic, as they are permeable and able to be influenced by other Discourses. A crucial component of any literacy is the ability to move beyond a surface-level interaction with the text of the discipline to be able to make connections to one's own life as well as the text's purpose and audience. Through these deeper connections with the text the reader can co-create the meaning through dialogic discourse (Liberg, Geijerstam, & Folkeryd, 2011). It is only through this kind of dialogic co-creation of meaning that individuals can question and transform their world – literacy is not simply the engagement with a system of symbols of codes. Instead, a critical, or emancipatory, perspective gives individuals the agency to change their social conditions, or even society itself (Martins, 2011). "Being literate involves, therefore, the possibility of becoming aware of one's own socioconceptual horizons as well as relating individual and social levels" (Martins, 2011, p. 98).

There is, therefore, a reciprocal impact on society in which literacy can shape society and social conditions, and changes in society – for example in technology or economics – can modify our very conceptualization of literacy (Martins, 2011). Literacy is dynamic and highly contextual (e.g. Brandt, 2001), and because of the intimate connection between literacy and contextual factors and different societal demands placed on individuals there may not be a unique definition of literacy (Martins, 2011). Instead, there are a number of relevant *dimensions* of literacy proposed by Soars[4] (as cited in Martins, 2011), for example textual, literary, political, sociological or discursive that could be used to study the concept. In the educational dimension, we see a large role of communication, and the centrality of language, to the development of knowledge (Kelly, 2011). Language, in turn, can be described in terms of its

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[4] I could not find an English translation of this article, so I am using the summary from Martins, 2011

dimensions, for example genre, abstraction, lexical density, logical relations, objectivity, and multimodality (Liberg, Geijerstam, & Folkeryd, 2011).

Literacy, along with its dimensions and its components, are highly complex, dynamic, and shifting. However, a tentative definition can be constructed from the components described above, with enough room for its dynamic nature within its bounds.

Literacy is the active participation and engagement in social Discourses, a co-creation of meaning through deep and personally meaningful interaction with text. It is built upon, but extends past, simple engagement with oral or written text. It is inextricably linked to culture and context, meaning that no two literacies will result in the same phenotype, or visible surface-level traits, but they all retain the fundamental notion of active and meaningful interaction with social Discourses. Finally, literacy has a reciprocal impact on society, in which societal changes will result in a shift in the definition or expression of literacy and as a result of literacy practices individuals can change their social conditions or society itself.

What Does this Mean for Scientific Literacy?

The literacy component of SL is incredibly important to keep in mind when assessing its meaning. Language has an essential role in the science learning process (Aduiz-Bravo, Chion, & Pujalte, 2015); there is a growing view that "there is no possibility of learning science without learning the literacy practices of science" (Norris & Phillips, 2015, p. 950). This includes and extends beyond simply reading and writing about science: "students must not only understand the main concepts implicated in the theories and models and grasp the scientific vocabulary, they also have to be able to apply the necessary language structures and patterns and use the correct discursive tools and rhetorical strategies." (Aduiz-Bravo et al., 2015, pp. 942-943)

Thus, the language of science, just like any other language, is more than the sum of its terms. It contains abstract concepts infused with meaning created through a distinct scientific culture. There is a shared history of meaning, dating back thousands of years, that is slowly unveiled as one is acculturated into the scientific community that "has its own representations, methods, ethos, and jargons" (Aduiz-Bravo et al., 2015, p. 942). To speak the language of science is, therefore, not the same as to understand the nuanced and implicit connotations of *what* is actually said. And yet in formal educational settings explicit references to the distinct culture and assumptions of the scientific enterprise are notoriously absent, and at best remain implicit (e.g. Abd-El-Khalick, 2008). We expect new language learners in the sciences to somehow gain an explicit appreciation of this shared history through engagement with terminology and exposure to decontextualized concepts, and yet this history of shared meaning, the shared culture of science, is *essential* in understanding the key aspects of nature of science – these are the assumptions, practices, and shared understandings intrinsic to the fields of science.

> Language [including the language of science] is not just a symbolic system of resources for communication, but it is also a constitutive element of social practices, identities, relationships between subjects, and relationships among subjects, institutions, and knowledge. Likewise texts contain traces of both social and historical processes of meaning-making and cannot be conceived of or understood without reference to the processes of their production, distribution, and reception in social practices. (Martins, 2011, p. 92)

Literacy does not involve the parroting of phrases back in the correct intonation and order, or even the ability to apply certain terms and phrases in the correct context. It involves entering into the ongoing cultural conversation, dating back to the inception of the language. Soares breaks these ideas into two contexts for using the term literacy, the first being similar to the more canonical viewpoint of literacy as reading and writing. This is the communicative dimension. The second refers to the integration of social practices, similar to emancipatory literacy (in Martins, 2011). In the case of science, this translates to two distinct and interrelated literacies: conceptual and epistemic. Conceptual literacy involves the understanding and application of the terms and concepts that first spring to mind when thinking about science, such as genes, evolution, and energy. This is the *content* of science. To be conceptually literate (though to who this would apply can be contested) one would understand, for example, that a gene is a set location on a chromosome, comprised of a set of nucleic acids, that codes for a specific protein. They would understand how the gene can change over time, what this will mean for gene expression and resulting phenotypic expression, and how this relates to other larger processes such as evolution, population genetics, physiology, and behavior. This is akin to the use and application of idioms and phrases in a new language. But to truly understand these idioms and the layers of meaning behind each phrase one must also understand the history of shared meaning of this culture. This is the epistemic literacy of science.

Epistemology involves the assumptions of the field regarding what constitutes knowledge and how to generate that shared understanding. In science these notions are intimately tied to historical constraints from technology and society. Forces external to science such as religious paradigms, societal norms, and technological advances have shaped what is considered knowledge (e.g. Kuhn 1996/1962, also Kuhn 1985/1957). Scientific knowledge is generated through observation and experimentation, but the methodologies and notions of best practices stem from philosophy (e.g. Neurath, 1929). It is this hidden culture, the influences external to the everyday practices of science itself, which shapes the meaning of scientific ideas. It is only when one understands that this language is distinct and meaningful, and yet only one of many different ways of understanding the world, and that these interrelated forces produce a way of knowing that is concurrently meaningful and imperfect, that one can be epistemically literate (and again, to whom this applies can be contested). But how does fluency in the language of science relate to what science actually is; are these the only dimensions of science?

The Science Component of Scientific Literacy

What is “Science”?

This section is intentionally brief not because of its unimportance to the definition of scientific literacy, but because a comprehensive discussion is beyond the scope of the current paper; to capture all of the complexities of *what is science* would fill an entire volume (if not several), as this question has been vehemently debated for centuries. And yet, to my knowledge, no comprehensive volume or keystone paper exists that synthesizes or summarizes this question. Further, what *science* is and entails has shifted dramatically over the course of history (e.g. Kuhn, 1985/1957, also Dunbar & Klahr, 2012), and its exact bounds are still disputed even presently. The parameters of this definition are within the purview of philosophy, specifically the demarcation between science and pseudoscience (e.g. Feyerabend, 1998; Kuhn, 1970; Popper, 1992). These demarcation criteria are infused with epistemological and ontological assumptions about the world (for example, Popper’s demarcation criteria as the ability to falsify one’s claim, paralleling his epistemological choices and specifically countering induction (1992)); these and other aspects of nature of science have produced an expansive literature base debating what science is. Because of this, there is “no single, universally accepted view of science [emerging] from a consideration of the literature” (Hodson, 1991, p. 21). Therefore, while it is incredibly important to define what science is, this would be an endeavor better suited for future studies that can delve into the philosophical underpinnings of this construct and the myriad papers dedicated to the topic. A formal explication of the science component of SL would need to encompass all aspects of the scientific enterprise, including these areas of dispute.

Despite this lack of consensus, there are several epistemological constructs underlying science that are relatively agreed upon (e.g. Abd-El-Khalick, 2008; Hodson, 1991). These are briefly summarized below from Abd-El-Khalick (2008, Table 1, pp. 838-839):

- scientific claims are derived from or consistent with observation;
- all observations are steeped in the theoretical commitments of researchers, meaning the same phenomena can be interpreted differently depending on the observer’s theoretical commitment;
- no natural phenomena are directly accessible to observation, as they are always understood through mediating assumptions, theoretical frameworks, or our perceptual apparatus;
- observations and inferences are distinctly different;
- scientific knowledge is never absolute, and yet is also reliable and durable;
- there is no “one” scientific method;
- laws and theories have specific meanings in the sciences;
- science is a human endeavor, which involves elements of human creativity and sociality;
- science is embedded in our social and cultural world, and is thus impacted by religion, philosophy, economics, and other factors that can shape what is considered to be an acceptable explanation;

- knowledge is socially negotiated within the scientific enterprise through a variety of established gatekeepers.

Added in a later iteration is the intersection with technology (Summers et al. 2016)

- science impacts the development and funding of technology;
- advances in technology shape the very nature of explanation and impact scientific discoveries

Hodson (1991) suggests focusing on these kinds of consensus principles for designing formal curricula, and these elements of nature of science are what I will focus on in this paper as the starting point for what science is. These principles shape scientific thinking, which entails both the *content* of science, “reasoning about such entities and processes as force, mass, energy…” and its *reasoning processes* such as hypothesis testing, deduction, and causal reasoning (Dunbar & Klahr, 2012, p. 611). These aspects of scientific thinking, while very similar to everyday thinking, have lead to scientific breakthroughs and achievements throughout the history of science.

First and foremost, though, science is a way of producing knowledge about the natural world. While the exact bounds of this and the means by which this occur is contested, the term science itself has meant *knowledge, knowing, book learning, experiential knowledge, collective human knowledge*, and *knowledge (of something) acquired by study* over the history of science, since the 14th century (science (n.), n.d.). This reflects the centrality of science as a way of knowing throughout the history of the discipline.

Therefore **science** is one of many ways of producing knowledge about the natural world. It is a social and human enterprise that is infused with elements of culture, creativity, and human subjectivity resulting in knowledge that is both durable and tentative. Scientific thinking underlies this enterprise, with a mixture of both content and reasoning processes driving scientific progress and innovation.

What Does this Mean for Scientific Literacy?

This complexity and ongoing debate at the philosophical level means that science is certainly not a “primitive term” (Chaffee, 1991, p. 7), with its meaning commonly understood or assumed, though it is often treated as such. What science is or entails is rarely explicitly addressed in the SL literature, yet it is these unspoken components of science for which they posit their readers should be literate. This paucity of explicit definitions regarding science itself is unsurprising, given the complexity of the topic. However, it seems an important first step to explicitly address what is *science* when deciding how to teach science or to what level the public should understand this field. If it is not explicitly defined, how will this information be conveyed to learners or educators of science? Some scholars (e.g. Martins, 2011) have alluded to the implicit or tacit nature of learning about science through acculturation into the scientific community, by engaging in this culture as an active participant. I by no means exclude this as a means by which someone may become scientifically literate. However, by engaging with science in the classroom, with the associated *classroom* culture and a *non-member* as the authority figure (though there are a minority of teachers that are members, as previously active researchers turned educator) the conditions for this acculturation have been reduced to a representation of the scientific culture, at best. At worst this is a far cry from the scientific enterprise, and therefore explicit communication of what science is and entails is absolutely necessary. The natural first step towards this explicit communication is a definition of *science*, or a discussion of the components of science, no matter how contested. Importantly, this will need to be directly applied to its practical application in education to be able to inform how this impacts SL. Even with a broad and contested definition of science, there are many elements that can be drawn from its consensus principles. It is a way of knowing, there is a reciprocal impact on/of technology, it is a human endeavor, there are many reasoning processes such as critical thinking and hypothesizing, there are multiple distinct genres, and many other elements that we can use to understand the impact of science on scientific literacy. The question is, what, if any, of these elements are utilized in the definitions of scientific literacy in the literature. Even more importantly, how are those elements connected to literacy to construct a comprehensive definition of SL?

Scientific Literacy in the Literature

Historical Roots of the term Scientific Literacy

As early as the 17th century public knowledge of science and the scientific enterprise was a pervasive goal (Bybee, 1997), but this notion was not yet formally linked to the term “scientific literacy”. By the middle of the 18th century there were a handful of references to “scientific literacy” (Bybee, 1997), but it was not until Hurd’s well-known publication in 1958 the term became commonly used in the science education community. It was no coincidence that this occurred after the launch of *Sputnik*, during a time of national turmoil; this link was even acknowledged by Hurd (1958) himself. *Sputnik* symbolized the denigration of our national status, and deflation of our perceived superiority. This was a shock that sent reverberations through the foundations of our citizen training, formal education. The response to this upheaval was a focus on the disciplines of science and technology, and by extension public understanding of science.

From this confluence of events, SL was transformed into its contemporary usages as main goal of science education, a “rallying symbol” for reform, a purpose, and a slogan (Bybee, 1997, p. 48). There was an explosion of research into SL resulting in this term becoming an amalgam of goals, dimensions, types, competencies and components. As early as 1962, only four years after its solidification as a term in science education, there were calls to unify the highly divergent goals (Bybee, 1997). And yet, in the five decades since its inception there has yet to be a consensus on what should be included in the definition of SL (e.g. DeBoer, 2000, Snow & Dibner, 2016). DeBoer (2000) found at least nine distinct uses of the term with only “a broad and functional understanding of science for general education purposes” in common (p. 594). This says nothing of the sheer number of definitions of SL. Norris, Phillips, and Burns (2014) found that from 2000-2014 alone there were 74 articles with an identifiable definition of SL. Even internationally, SL is a “well-recognized educational slogan, buzzword, catchphrase, and contemporary educational goal” (Laugksch, 2000, p. 71).

> Despite the widespread enthusiasm for science literacy, writ large, and the prominence of a few widely cited definitions, none of the fields concerned with science literacy have managed to coalesce around a common conception of what is meant by the term (Snow & Dibner, 2016, p. 28)

Contextualizing the Polysemy

There are many ideas as to what could have caused this polysemy, and how to contextualize the many uses and conceptions. There have been many individuals and groups that have taken an interest in public understanding of science over the last several decades, each with their own vested interests and objectives. These contradictory objectives have likely both been shaped by and had a hand in shaping the various educational paradigms, which have in turn molded the definition of scientific literacy. To provide a small picture of the theorized factors influencing this polysemic term, the ideas of three prominent SL researchers are discussed below.

DeBoer (2000) takes a historical approach, reviewing the history of SL, in use and definition, even before its inception as a term in 1958, connecting its shifting definitions with the evolving trends in education over time. During the Cold War era, when there was a myopic focus on training the next generation of STEM researchers and leaders, there was a concurrent pragmatic focus to the SL definitions, on disciplinary content. During the 1970s-1980s, there was a shift back to a more holistic view of science, including its relationship with society and its everyday applications. The content of science was not always the main focus, and for some (the science-technology-society (STS) curriculum advocates), social components were even more important than disciplinary content. The pendulum swung back to content-based curricula in response to the 1983 report *A Nation at Risk,* from the Regan administration. This standards-based reform focused on higher accountability for schools, meaning high-stakes standardized testing focused on content knowledge (DeBoer, 2000). To "clarify the goals" of this new movement, the AAAS published *Science for All Americans* (p. 589) which snowballed into the National Science Education Standards and then the Next Generation Science Standards, making the way for the current era of standards based curricula focused on educating all students (or No Child Left Behind). The shifting educational reform eras lead to a broader and broader definition of SL that now includes "everything possible in the definition" (DeBoer, 2000, p. 594). Within this amalgam, there is a common thread: "The one specific thing we can conclude is that scientific literacy has usually implied a broad and functional understanding of science for general education purposes" (DeBoer, 2000, p. 594).

These pendulum swings have also resulted in a deep tension between the content and application of science as the main focus of science education. Bybee (2015) discusses the contradictory goals of training citizens and the next generation of scientists that has persisted over the last several decades. His conception matches that of Roberts' (2011) Vision I and

Vision II, a focus on the discipline of science itself (internal, or Vision I) versus the impact on our everyday lives (external, or Vision II). This rift poses a significant challenge because of the enormous impact of this choice on what students and teachers learn about science content, but also "the attitudes they develop, the skills they acquire, and their ability to competently identify, analyze, assess, and respond to life situations" (Bybee, 2015, p. 945). Bybee suggests that even those headed towards careers in the sciences must be able to apply this knowledge to their everyday lives, and thus the current focus on content (Vision I) must be supplemented to include connections to society and individuals' lives (Vision II). However, this is a post hoc distinction, with this range of goals and foci all falling in a continuum, and under the same term.

One of the factors that Laugksch (2000) posits can lead to the myriad meanings and interpretations of SL are the many different groups that have vested interests in SL. While many other researchers focus on the science education community, Laugksch extends his analysis to other interest groups, such as science communicators, public opinion researchers, and sociologists of science. Each of these groups have their own conceptions of what it means to be scientifically literate, the best methods of achieving and measuring SL, and who should be included in these interventions. I agree wholeheartedly that there is a significant divergence in goals stemming from different interest groups. However, what Laugksch does not account for is the impact of scientists themselves on SL definitions, curricula, and policy. The one category into which scientists may fall, *science communication,* is casually discounted as an extension of the conceptions of other interest groups and not analyzed further. However, I will argue below that while the conceptions of scientists do overlap with those of educational researchers, there are disciplinary differences in how SL is conceived, and this could lead to conflicting messages for the public about science. This in and of itself could be the root of some of the polysemy seen in the literature, but cannot be interpreted in isolation of the historical trends that may have resulted in, or from, these different interest groups.

Lack of explicit connections between Science, Literacy, and SL

What is missing from all of these definitions of SL is an explicit connection to the components of the term: science and literacy. There is no shortage of authors that delve into the significance of literacy for public understanding of science, meaningfully connecting literacy

Table 1 – definitions of science in select SL publications

Author, Year	AB	IM	EX	definition of science
Hurd, 1958	x			absent
Raymo, 1998	x			absent
Devlin, 1998	x			absent
Miller, 2004	x			absent
Aikenhead et al., 2011	x			absent
Bybee, 2015	x			absent
Shen, 1975		x		"For brevity's sake, whenever I use the word 'science' without further enumeration of its contents, I mean both basic and applied science, including technology and medicine. Similarly, the words 'scientific' and 'scientist' are meant in the broadest sense." (footnote 2)
Burbules & Linn, 1991		x		There is no explicit definition of science, but many components of NOS are intertwined and implied throughout the essay
Kelly, 2011		x		talks about how there are questions about what "counts as science", but this is in reference to what is included in curricula
Martins, 2011		x		"the inherently multimodal nature of scientific knowledge and discourse. From the first steps of the conceptualization of scientific phenomena until the final stages that correspond to the dissemination of consolidated results, science deploys a variety of semiotic resources" (p. 99)
Branscomb, 1981			x	"'knowing how to know' is not a bad definition [for SL], for 'science' is derived from the Latin root meaning 'to know'…" (p. 5)
Bybee, 1997			x	"science is a fundamentally human enterprise, which has involved men and women of various cultures" (pp. 114-115)
Maienschein & students, 1998			x	"science is a process carried out by humans who work in a social context" (p. 917)
DeBoer, 2000			x	"science is a particular way of looking at the natural world" (p. 592)
Laugksch, 2000			x	"science is an intellectual enabling and ennobling enterprise" (p. 86). "science is the distinctively creative activity of the modern mind" (p. 86)

Table 1 (cont.)

Snow & Dibner, 2016	x	"science is a way of knowing about the world. At once a process, a product, and an institution, science enables people to both engage in the construction of new knowledge as well as use information to achieve desired ends" (p. 1) "science is one way of knowing about the world" (p. viii) "[SL individuals are] aware that science is a human enterprise with strengths and limitations, and appreciate the ethics that guide scientists in their work" (p. 33)

Note: AB = definition absent; IM = implicit definition(s) of science; EX = explicit definition(s)

with SL. However, there is a large gap in the literature connecting science to SL, and an even larger dearth of meaningful investigations into the connections between science and literacy, and what this means for SL. In the SL literature, a large number of authors don't even speak to what science is, and many that do broach the topic do so implicitly, with no explicit definition of science (Table 1). Those that explicitly mention what science is typically only include one or two consensus principles and do not expand on what this means for SL. There are, of course, exceptions. While Burbules & Linn (1991) do not explicitly define what science is, their entire paper is framed around the impact of nature of science on SL. Further, *Science for All Americans* devotes an entire chapter to nature of science in their recommendations for SL (AAAS, 1990).

Relationship Between Science, Literacy, and Scientific Literacy

Martins (2011) argues, and I agree, that the complexity of the SL definitions can be explained by an analysis of the concept of literacy. But I would add to this that we must analyze the concept of science concurrently. In particular, what do the two have in common? Are there natural intersections between the two? The language of science sits directly between science and literacy, and there are many other overlapping elements in these two sets of literatures, and yet only one researcher (Branscomb, 1981) explores the intersection between science and literacy and what this means for constructing a definition of SL. Even this is only a cursory connection between the etymology of its components. A deeper analysis will help to contextualize the different definitions of SL, and what, exactly, deviates and overlaps between them. In particular, in what areas these definitions are plotted can help to understand the richness or uni-dimensionality of certain definitions – for example, what about elements of the definitions that don’t intersect with either science or literacy? How are these related to SL? Finally, are there any discipline-specific differences in where these elements fall; for example, are definitions coming from the sciences going to populate the “science-only” area more frequently than those from education? To answer these questions, the elements of science and literacy must be compared and mapped with respect to one another.

Natural Intersections of Science and Literacy

There is much more in common between science and literacy than the use of language to communicate scientific results, and beyond understanding some vocabulary to be able to engage in the language of science. Both are embedded in social practice, context, values, and beliefs that shape how individuals view the enterprise and the resulting products. The definitions provided in the sections “the literacy component of scientific literacy” and “the science component of scientific literacy” were compared and contrasted to determine points of overlap and deviation between science and literacy – the natural intersections between these definitions outside of the SL literature. These findings are plotted on Figure 1 and described in some detail below.

Science and literacy are both shaped by social conditions, but can also be used to transform and be liberated from these social conditions. This means that both definitions are evolving as they are shaped by, and work to shape, society. This transformation requires a deep connection, beyond surface understanding, to co-create meaning or to engage with meaning on a personal level. There are surely more points of overlap than are even represented on Figure 1, and some of this ambiguity is represented by asterisks, in which there was no direct support for overlap in the literature, but it would be reasonable to think that this may be a point of overlap, nonetheless. There are clear points of divergence as well, as each is its own characteristic enterprise. There are also points at which these mergers could be contested, for example the role of alphabetic literacy in SL:

> Such an effort should be closely coordinated with plans for alphabetic literacy (reading and writing). It is interesting that alphabetic literacy is not a prerequisite for scientific literacy: the latter can be achieved through speech and pictures without writing. In fact, the urgency of practical scientific literacy will in some cases justify its taking precedence over alphabetic literacy in development planning. (Shen, 1975, p. 47)

While Martins suggests that the literacy component of SL is a "metaphorical appropriation from the field of language and literacy studies" (Martins, 2011, p. 91), from the degree of overlap between science and literacy, and the fundamental role of language and communication to any social enterprise, I would argue that there is a strong influence of literacy on science itself, and it should therefore have a strong presence in SL. But, how does this overlap compare to what is found in the literature regarding SL? Similarly, components of science should be distinctly integrated into the SL definitions in the literature.

Methods of Selection and Discipline Assignment

There is a large and diverse literature about SL, coming from many different disciplines. My analysis focuses on only two disciplines, science and education. While there are other means by which the public engages with science, these two are the largest avenues through which SL definitions can impact the public, through the traditional formal K-12 curriculum, as well as formal and informal interactions between the public and scientists, which are named Broader Impacts by the National Science Foundation. Given the sheer number of conceptions of SL, it was necessary to pare down the literature base to a smaller number of unique definitions. For the purposes of this analysis I conducted a snowball sampling technique to acquire literature (using an initial search through Google Scholar and then collecting further references from the literature cited of each successive paper). As can be seen in a comparison to the larger literature review, these definitions are fairly representative of the variety of definitions stemming from the sciences, education, and philosophy. The exception to this inclusion methodology was the intentional inclusion of Science for All Americans (AAAS 1989/1990), which was chosen because of its tremendous impact on education at a national level (the impact of which will be expanded on in the section “the significance of a single definition”). Each paper was read in full and all content related to SL was recorded as quotations. The discipline to which each definition is attributed was not known beforehand, and was determined by which field the primary author actively contributes or the department in which he or she is a faculty member. In only two cases was this an issue. Nicholas Burbules (Burbules & Linn, 1991) works in the intersection of education and philosophy; he is a faculty in education, received both of his graduate degrees in philosophy, and actively contributes to both fields. He is placed under education, as this is his faculty position. The second was the AAAS (AAAS, 1990). In the preface (p. *x*) Science for All Americans states that this work is the “result of a three-year collaboration involving several hundred scientists, mathematicians, engineers, physicians, philosophers, historians, and educators”, however, the content was constructed by “scientific panels” (p. *xxii*) and they claim that this book “represents the informed thinking of the science, mathematics, and technology communities as nearly as such a thing can be ascertained” (p. *xxiii*). This was therefore placed under science, but could be considered as a product of education (or other domains) as well. The “other” category pertains mostly to the history and philosophy of science. See Appendix 1 for full quotations of all analyzed materials, split by domain.

Each definition was coded for elements of science, literacy, both, or other, with the code being the specific element aligned with the quotation. It was often difficult to distinguish what materials consisted of a *definition* of SL, or could be counted as an *objective* of SL (Table 2). For analysis purposes this difference was not taken into account, as both were explicitly outlining SL. In addition, there were what I call *supporting materials* that expand on or further explain either the definition or objective without saying explicitly what SL is (definition) or its aims (objective). If these were analyzed separately from the definition or objective they were included in Appendix 1. These codes were then analyzed for holistic differences between disciplines, by looking at the trends of where each discipline was plotted against science and literacy (Figure 2) as well as what types of codes were used for each definition within either science, education, or other (Appendix 2).

Table 2 – Codes of SL Definitions

Code	**Description**	**Example**
definition	what SL *is*	“Scientific literacy is…”
objective	the *aims of SL*	“Individuals who are scientifically literate should be able to…”
supporting materials	expands on or further explains objective or definition	"SL is seen not just as a pedagogical issue but also as a political issue"

The Intersection of SL, Science, and Literacy

While the specific elements left out of or incorporated into SL definitions in the literature is interesting, and should be explored further, it is the number of elements populating each area, and their relation to the different disciplines, that is most informative (Figure 2). It is intuitive that there would be several elements of literacy that have nothing to do with either science or SL, since literacy applies to many domains. However, it seems that there should be an intimate relationship between science and SL, with very few elements of science not overlapping with SL. There are certainly components of the scientific enterprise that are not necessary for the public understanding of science, but the question is how many and what? Where either disciplines or individual definitions draw this line is interesting. In particular, the definitions from education have a much larger overlap with both science and the intersection of science and literacy, than science itself. Surprisingly, there are even items populating this intersection between science and literacy that are not incorporated into any SL definition, even the highly important reciprocal impact of society and culture. Also interesting are the number of elements populating the intersection between SL and literacy, as there are apparently several components of literacy that are required to be scientifically literate, that are not a part of the scientific enterprise (e.g. discourse type, metacognition, co-creation of meaning, habits of mind).

SL Elements not Intersecting with Science or Literacy

What about the elements populating only the "scientific literacy" portion of the diagram (Figure 2)? These are not explicitly connected to either science or literacy, nor the intersection between the two. While these are *about* science and/or literacy, an element such as "economic growth" or "affect/emotion" are not *characteristic* of either one. For example, there is a clear connection and argument for "common-sense thinking" being related to science. In fact, there is a large overlap between everyday thinking and the kind of thinking found in the sciences (e.g. Dunbar & Klahr, 2012; Shen, 1975). Common-sense thinking is not on its own "scientific", however, there is a large overlap in how scientists think while conducting research (even for large breakthroughs) and how they, and others, think in their everyday lives. This, then, is a component of everyday thinking. Everyday thinking can be thought of as a link between science and SL[5], bridging the gap between the two. There are several such links, identified from the elements populating "scientific literacy only", shown in Figure 3. There are at least two ways to visualize these links. Many of these links can connect SL with both science and literacy, and are not exclusive to just science or literacy. For example, everyday thinking connects SL to science, but it likely plays a large role in literacy as well, though one that thinks in this way cannot necessarily be called literate. Therefore rather than links connecting only science and SL, or literacy and SL (Figure 3A), these links may span literacy, science, and their intersections (Figure 3B).

This parallels the two visions of SL that Roberts (2011) discussed, but rather than an entire definition focusing within or outside of the scientific endeavor, certain elements fall within or outside of science and literacy. Within one definition, though, are there at least some elements of science, literacy, or their intersection? Does the proportion or inclusion of any of these change depending on the discipline? What might these patterns mean for how the public engages with science?

Disciplinary Trends in the Intersection of Science, Literacy, and SL

I analyzed the definitions for disciplinary differences in the patterns of inclusion and exclusion of science and literacy in SL definitions, by mapping the elements onto a Venn diagram (Figure 2). There are clear qualitative, holistic differences between the disciplines of science and education, in the distribution of elements across literacy, science, and their intersections. Definitions stemming from education are, in general, much more balanced, with elements in each area of the diagram. Additionally, there are very few elements that are included in definitions from the sciences that are not also covered in education. Definitions from the sciences, on the other hand, have very few elements within the intersection between science and literacy, and only one in literacy. The two elements in the intersection of science and literacy are concept formation and vocabulary, both of which are closely aligned with the content of science. This means that even when incorporating literacy into their definitions, this

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[5] And perhaps a bridge to SL: "I think the public understanding of science will be advanced if science as a whole does not appear so forbidding to the layman, and science will not appear so forbidding if the layman realizes that exactly the same common sense logic governs all of science and the issues surrounding science as governs our everyday thinking, reasoning, and decision making." (Shen 1975, p. 52)

is in service of the content of science. This focus on the content of science is also reflected in the individual definitions from the sciences (Appendix 2, Table 6); most definitions have content as their focus, with the majority of other science elements coming from a single objective (from Devlin, 1998). A parallel trend is seen in the definitions from education – a single objective from Burbules and Linn (1991) addressed the majority of the science elements. However, almost all of the education definitions have elements from the intersection of science and literacy, as well as several literacy elements. While the education definitions are more balanced overall, incorporating elements from both science and literacy (or their intersection) in all of their definitions, there is still large variation in what and how many elements are included in each individual definition. Within each discipline, the focus of an individual definition may be on science, literacy, or even a linking dimension. Further, there are large differences between disciplines, at both the fine and coarse level. Given the tensions described by Bybee (1997) between scientists and educators in their educational foci this is unsurprising; scientists typically highlight content while educators stress educational issues. These foci are validated by the disciplinary trends above. If there is a tension between content and other SL components, an important question to investigate is how these varying definitions affect public understanding and perception of science.

The Significance of a Dynamic Definition

It is important to consider the potential impacts of these large variations in definitions. Will a dynamic conception of SL, with a focus on different elements of science, literacy, or other dimensions translate to differences in practice for educators or in the conceptions of science held by the public? Does this variation even matter if certain definitions are disproportionately impactful in educational or other settings?

The Significance of a Single Definition

While there are many definitions of SL stemming from the fields of education and science, one stands alone as having, by far, the greatest impact on education at a national level – this is the definition coming from the AAAS. *Science for All Americans* was the result of the combined effort of hundreds of scientists and educators to compile “a set of recommendations on what understandings and ways of thinking are essential for all citizens in a world shaped by science and technology" (AAAS, 1990, p. *xiii*). The content of this book, held in high esteem by educators, highly impacted a curriculum framework from the National Research Council.

> This framework builds on the strong foundation of previous studies that sought to identify and describe the major ideas for K-12 science education. These include Science for All Americans and Benchmarks for Scientific Literacy (1993), developed by the American Association for the Advancement of Science (AAAS), and the National Science Education Standards (1996), developed by the NRC. The framework is also informed by more recent work of two of our partner organizations: the AAAS (in Project 2061 especially) and the National Science Teachers Association (particularly the 2009 Anchors project). (NRC 2012, p. *x*)

The result of this framework was the first (and only) set of national science standards in the United States, the Next Generation Science Standards (NGSS). While these standards are not compulsory, it is the intent that each state that chooses to adopt the national standards must do so fully such that the standards cannot be modified. Even if states only partially adopt the standards, this still means that the language in this single document can have a large and national impact on science education. While only 16 states have fully adopted the standards so far, meaning the standards are implemented as-is without any alterations to the document, 26 states participated in the development of the document (Next Generation, n.d.), making it more likely that they will either fully adopt these standards or cut and paste certain (if not most) elements out of convenience. Several states have already done this, partially or unofficially adopting the NGSS (such as Illinois, Massachusetts, and Missouri), integrating components into their own state standards. Similarly, it makes the most fiscal sense to produce textbooks that align with the standards of several states, and to make these textbooks widely available even in states that had not officially adopted the NGSS. It is well documented that teachers often develop their curricula directly from their textbooks (e.g. Abd-El-Khalick, 2008). Further, individuals or organizations developing curricula would make a larger national impact by aligning their curricula with the NGSS. These curricula will likely be implemented in several states, not just those that have fully adopted the NGSS. This single definition of SL, then, has an overwhelming impact on national frameworks, standards, curriculum guides, instructional materials, and assessments – all impacting student understanding and interpretation of science. And yet this definition contains very few elements of science or literacy, focusing mostly on the content of science (see also Roberts, 2011). I would be remiss if I did not reiterate that this focus on content is in their *explicit* definition of SL. While this focus may not necessarily reflective of their document as a whole, their explicit definition of SL, and not how the definition is applied, is the component that is of most interest in this explication.

Broader Impacts in the Sciences

It is important to consider that, while extremely influential, national and state standards are not the only avenue for conceptions of SL to reach teachers and students. Educators interact with science in their own higher education, and both students and teachers can engage with science through other means such as informal learning environments and mediated messages.

This means that what scientists understand SL to entail will have a large impact on both formal and informal education. Faculty and graduate students in the sciences are tasked with teaching and designing undergraduate courses in the sciences, and their conception of what the public should understand about science will greatly impact how they design their courses. Scientists are often asked to collaborate in the development of curriculum guides as well as other educational materials such as textbooks and lesson plans. Further, a compulsory component to any large grant through the National Science Foundation is "Broader Impacts", in which researchers interact formally and informally with the public to teach about their research and science in general. As these interventions are mandatory for these highly esteemed grants, how these researchers convey science to the public through informal outreach, citizen science, educator/scientist partnerships, etc. will likely be reflective of their conception of what the public should know about science. These different conceptions of SL could result in very different outcomes for the public. What is the impact of these different, and potentially conflicting, messages about science?

Conflicting Messages for the Public

"Different conceptions of language will lead to quite diverse meanings for literacy" (Martins, 2011, p. 92). Given the intimate connection between science and literacy, it is not too far of a step to say that different conceptions of SL will lead to quite diverse conceptions of science itself. Different conceptions even of the *language of science*, could be incredibly impactful, as this is intimately connected with the culture and nature of science itself. As discussed above, there is a reciprocal impact of society and literacy, as well as society and science. So a shift in conception of the language of science can lead to a shift in the meaning that is co-created between those that produce it and those that engage with it. “The inextricable relationship between language and society suggests the possibility that linguistic/discursive change could indicate or lead to social change” (Martins, 2011, p. 92). Conflicting messages about the language of science could lead to a large-scale change in how the public relates to and understands science, resulting in a larger societal shift in public understanding of science. And this is only one element of scientific literacy. Therefore, to which of these many different conceptions of SL educators subscribe could make a large difference in the conception of the fundamental nature of science for the public. There is large variation in which elements are highlighted, incorporated, and left out of definitions of SL, but what we don’t know is what kinds of changes, or how many changes, could result in differential understanding of science. The terrain of SL needs to be examined to understand the effect that each of its components can have on the public’s perception and understanding of science.

Components of Scientific Literacy: A Theoretical Typology

Because of the breadth and diversity of SL conceptions, and the current polysemic application of the term, there are diverse and numerous elements associated with SL, as can be seen by the highly populated Venn Diagram in Figure 2. These elements, or sub-components, can be grouped together to form larger components of SL that encompass subsets of sub-components. For example *Beautiful, exciting, fun*, *Art-like appreciation for science*, and *Creative nature of science*, all share that they describe “aesthetic qualities” of science (see Table 3). These components are not meant to be comprehensive or final, but do reflect what is found in the literature regarding science, SL and the intersection of science and literacy.

Several of these components relate to one another, and form over-arching super-components. Similar to the two visions of Roberts (2011), there are some components that are more internal to the scientific enterprise, and others that relate to practical application of science, everyday use of science, or other aspects external to the scientific enterprise itself. This enterprise is broken up into *surface* and *deep*, representing the components of science that are either describing the activities or products of science (surface) or the driving forces and assumptions behind these activities (deep). Similarly, the connection to everyday life and society is divided into pragmatics and critical dimensions to represent the difference between utilizing science to solve everyday problems on an as-needed basis (pragmatics) with the transformative nature of a deep understanding of science and its relation to your everyday life (critical). There are several linking dimensions, which include components that are outside of, but connected to, science or literacy. Finally, a more comprehensive, broad component of philosophy of science was included separately from the pragmatic nature of science component, nested within the deep scientific enterprise super-component, as grappling with epistemological or ontological constructs that are not in consensus are beyond even an active researcher in the sciences, and is thus characterized as an expert-level super-component.

While elements of literacy are interwoven within most of these SL components, *foundational literacy* was included as a separate super-component given that navigating one's primary discourse is essential to acquiring the secondary discourse of science. What are not explicitly included are the social structures that must be in place to acquire any of the aforementioned components of SL. As Snow and Dibner (2016) stress repeatedly, individuals are not isolated in their educational experiences, there are social structures that can enhance or detract from their learning trajectories. These social experiences must be taken into account when considering how to define SL, and how these components interact to produce individuals, communities, and societies that are scientifically literate.

Table 3 – Components of SL

Super-Component	**Component**	**Sub-Components**
Foundational Literacy	Primary Discourse	Literacy Numeracy
Scientific Enterprise - Surface	Content	Shallow to deep, or unconnected to interconnected Entities, processes
	Terminology	General to specific Vocabulary specific to science
	Reasoning processes	Hypothesis testing Deduction Causal reasoning
	Language of science	Communicative dimension Discursive dimension

Table 3 (cont.)

	Knowledge production	science produces new knowledge
	Genres of science	Doing science (skills of science) Explaining events scientifically Organizing scientific information Challenging science Stable features associated with scientific practices (e.g. objective writing style)
Scientific Enterprise – Deep	Nature of science (pragmatic)	Relatively un-contested consensus principles (e.g. Abd-El-Khalick, 2008)
	A way of knowing	Strengths/limitations Limits of science Science vs. pseudoscience (demarcation) Relationship to other domains and ways of knowing One of many ways of knowing
	Sociality is central to meaning	Social construction of knowledge Co-creation of meaning Nature of science aspects (social enterprise, embedded in and shaped by social and cultural practices, dependent on social, political, and economic forces, social negotiation of knowledge)
	Never autonomous or neutral	Infused with individual subjectivities; societal and cultural practices; social, political, and economic forces; technological constraints and advances; context; morality, values, beliefs; affect and emotions; etc. Theory-ladenness of observations
Linking Dimensions	History of science	Scientific achievements Broad to narrow
	Aesthetic qualities	Beautiful, exciting, fun Art-like appreciation for science Creative nature of science Intellectual heritage
	Connection to other domains	Mathematics Technology Medicine Citizenship Economics Politics Philosophy (morality, values, ontology, epistemology, ideology)

Table 3 (cont.)

	Relationship to technology	Reciprocal impact of technology and science Multimodality
Pragmatics	Impact on decision making and everyday life	"Capacity building" (knowing-in-action) Inform personal decisions Solve practical problems, e.g. for health or survival Preparation for work-life
	Science, technology, and society	Solving problems at the interface of science, society, and technology (and their combinations)
Critical Dimensions	Centrality of language and discourse	Language central to knowledge production Science as a secondary discourse Impact of discourse types on SL
	Transformational	Reciprocal impact on society (ability to transform social conditions or society itself) At the individual level, can be applied for individual purposes, for example to inform personal decisions and to solve practical problems for health/survival Individual agency, liberation, metacognition, awareness of socioconceptual horizons
	Deep connection and/or understanding	Acculturation (*one way* to get this deep connection and/or understanding) Participation as a member
Expert-Level	Philosophy of science (broad)	Epistemology Demarcation criteria Ontology

Compatibility of Components

These components and super-components are *generally* compatible with one another. While there is a tension between, for example, the broad versus pragmatic notions of nature or philosophy of science, if one were to include the more comprehensive broad version it would subsume the pragmatic notions. Instead of being irreconcilable, these tensions represent the choices that individuals may have to make regarding which components, or the depth of these components, to support or include in their own definitions of SL. The systematic exclusion of certain components does not mean that they are *fundamentally* incompatible, simply that inclusion may not be necessary or desired for a particular context, culture, or goal.

Within each of these components there are several sub-components, and it is these elements that may be incompatible with one another. For example, many scientists are far removed from the idea of the co-construction of meaning, and would instead assume that the information on a page remains static (and fully comprehensible, given the right training) over time. This element, then, is at odds with the assumptions prevalent in the fields of science. However, what researchers in the sciences do intimately connect with is the social elements of nature of science. Therefore there are both compatible and incompatible elements within the component "sociality is central to meaning". It is for this reason, the potential incompatibility at the sub-component level, that I call this general compatibility. However, as stated above, general compatibility does not necessarily mean general agreement.

A Typology of SL

Which of these components, if any, are central to SL? Many definitions from the sciences stress the content of science, and include one or two components from the scientific enterprise (deep). Stressing content at the forefront means that this information is decontextualized from how and why that knowledge was produced. This would be a shallow understanding, and would reduce the ability of the individual to apply this information in novel settings. Similarly, an understanding of the nature of science devoid of content may lead to one becoming lost within this depth without tools to navigate or contextualize its complexities. Even an appreciation of the aesthetic value of science requires some grasp on science concepts and an understanding of the forces at play shaping the products of science. It is for this reason that I argue that any version of SL must include components of both the surface and deep scientific enterprise super-components. However, the number of components and depth to which these are included will depend on the context. The result of this is a shifting and interchangeable conception of SL that takes context into account. At its core there are at least six stable concepts that are hierarchically related to one another. While each super-component may vary in its centrality within a single SL definition, because scientific literacy is intrinsically focused on science, elements from the scientific enterprise (shallow and deep) will always be included, though it may not be the focus. Pragmatics and critical dimensions may need links to science or literacy, so this places linking dimensions as more of a central concept for SL. For example, in order to make healthy decisions in one's everyday life (pragmatic dimension) the linking concepts of epidemiology and medicine may be necessary, which thus requires a familiarity with the foundational science concepts underlying them. This results in a hierarchy of super-components, with the inclusion of lower super-components necessary when focusing on higher components. For example, if the focus of a definition of SL is on the critical dimensions of SL, at least one element from pragmatics, linking dimensions, and scientific enterprise (shallow and deep) should be included. This hierarchy is supported by a quote from Martins regarding the necessity to include all of these elements in emancipatory SL, which falls under the critical dimension.

> From emancipatory perspectives, the answer to the question of why we should promote SL is not defined solely by the nature of science or scientific activity but by the need to transform men and women into citizens. In this way, they reinforce views that school science is not just a didactically authorized version of scientific knowledge, but new knowledge that arises from an amalgamation of scientific, ethical, moral, cultural, pedagogical, and commonsense knowledge. (Martins, 2011, p. 98-99)

What elements each definition includes, then, will be dependent on its focus, objectives, and context, but in all cases it will be necessary to make a fully informed decision about what elements are excluded and why. Given the historic and present conflicting goals, research traditions, disciplinary expectations, and many other factors leading to the polysemy found in the literature, a fluid definition may be required to suit the context or needs of the students.

> Instead of defining scientific literacy in terms of specifically prescribed learning outcomes, scientific literacy should be conceptualized broadly enough for local school districts and individual classroom teachers to pursue the goals that are most suitable for their particular situations along with the content and methodologies that are most appropriate for them and their students. (DeBoer, 2000, p. 582)

There are many different conceptualizations of SL in the literature, and this typology is meant to be used as a tool for purposeful inclusion and exclusion of the many different proposed dimensions of scientific literacy.

Discussion

Scientific literacy is a dynamic, complex, and highly abstract concept that is context-dependent. While Roberts' (2007) notion of two visions dividing the definitions of SL was a good start, clearly there is even more complexity than a tension between two competing visions. This chapter has shown empirically that there are, in fact, several super-components that comprise SL, with many more components within. The number, type, and depth of complexity of components included within SL can vary depending on the context, and this may result in a drastically different conception of what *being* scientifically literate can mean and look like. By articulating the components that comprise SL, and creating a typology of the concept, I have attempted to make these context-dependent choices explicit to help understand the nature of these complexities and inform choices regarding which components to include.

There are myriad arguments for the necessity of one version of SL over the other, depending on the situation. I briefly touched upon the role that context plays in selecting certain components of SL, but I invite expansions, criticisms, and deep consideration of what components are central to SL and which are context dependent. What I would like to stress is that in this consideration we need to recognize *why* certain contexts may only call for certain components of SL - the exclusion criteria and reasoning should be explicitly laid out. It is for this reason that a critical examination of the components of SL themselves is also called for, so we can begin to move towards a complete landscape of SL components as a first step towards understanding the role that context will play in only utilizing a portion of this landscape in our definition(s).

Even after articulating what SL both is and is not, the issue remains of how one should assess whether an individual is scientifically literate. There are operational contingencies constraining the execution of such assessments, particularly in formal education. Content and terminology can be assessed quantitatively using multiple-choice tests, and are easy to administer large-scale. These concepts can be disseminated, catalogued, and assessed with ease. This comes with the tradeoff of a surface-level assessment, containing only a subset of the surface-level scientific enterprise components at that.

> Unfortunately, many middle-class mainstream status-giving Discourses often do stress superficial features of language. Why? Precisely because such superficial features are the best test as to whether one was apprenticed in the "right" place, at the "right" time, with the "right" people. Such superficial features are exactly the parts of Discourses most impervious to overt instruction and are only fully mastered when everything else in the Discourse is mastered. Since these Discourses are used as "gates" to ensure that

> the "right" people get to the "right" places in our society, such superficial features are ideal. (Gee, 1989, p. 11)

Many other components of SL must also be taken into consideration for a complete picture of scientific understanding, but these become increasingly difficult to assess. For example, how would one assess whether someone had an “art-like” appreciation for science? What would this actually look like in practice, and how could this be meaningfully included on a multiple-choice test? The question seems nearly as complex in both formal and informal settings. In a formal setting, how would one assess whether an individual was able to solve practical problems, unique to that individual, using science? In an individual or informal setting, how would that individual be able to assess, on their own, whether their grasp on science was sufficient to solve the problem or if there was a better solution that they had not considered? In the literature, even in the explanation of more esoteric concepts such as being scientifically “aware”, the practical application of these explanatory elements are still missing.

> When I say that all adults should be scientifically aware, I mean that they should base their opinion on fact and observable evidence rather than on prejudice or assumptions; they should be willing to change their opinions based on new evidence, understand cause and effect relationships, and appreciate how science is done—in particular understand the role played by observation and experiment in establishing a scientific conclusion. (Devlin, 1998, p. 559)

Being scientifically aware means that the individual should understand cause and effect relationships, but what then does an understanding of cause and effect relationships look like?

Each one of these elements presents its own unique challenges in operationalization, and contextual factors will likely provide more contingencies for how this could be applied or assessed. Further work will need to be done to connect each of these elements to practical dimensions, before assessments can be developed. Given the sheer number of elements encompassed under SL, this will be no small task. However, this distillation to lower order concepts, or operationalized terms that are tied directly to practical dimensions, is absolutely necessary, as there are numerous conceptions of SL in the literature currently[6]. This is unsurprising given the complexity and contested nature of both science and literature, each spanning multiple disciplines on their own. It is perhaps a result of the difficulty of defining

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[6] Aligning well with Chaffee (1991, p. 26)

lower order concepts associated with SL that more abstract, higher order concepts are most prevalent in the literature. These abstract concepts can be applied in many different ways in many domains, and this is likely causing the polysemy that is seen in the literature. To narrow down where and how to apply SL, we must first distill the essential, basic components of SL that are tied to practical dimensions. The typology listed above is a start to building this landscape, but it must be expanded on and further operationalized to be useful in practice. This will require empirical work, focusing on how context shapes or constrains the practices of educators, scientists, and learners as well as what each of these components looks like in practice. Importantly, the ties of SL to science and literacy cannot be ignored, and any consideration of what components are central or peripheral to SL should weigh the influence of each of these on what the public should know about science.

The dynamic nature of SL will likely have significant implications for development of curriculum, interventions, and informational materials, and especially for assessments. What will have to be empirically assessed is how do choices (within or outside of conscious awareness) of what components to include in a definition of SL *actually* translate to literacy among the public. Does this actually result in differential outcomes in public understanding of science? The first step is to understand how the major gatekeepers of the image of scientific literacy, teachers and scientists, conceive of scientific literacy. Do those outside of the SL bubble hold the same notions of scientific literacy as the researchers in their domain? It is possible that domain-specific differences in SL conceptions could remain at the theoretical level and not be representative of the active researchers and teachers that are disseminating science ideas to the public. Importantly, how do these individuals at the interface of academia and the public impact public understanding and perception of science? What impact does the focus on certain subsets of SL components have on public understanding of science? We are not short on ideas of what SL should entail, but many questions remain about the impact these varying definitions, and the choices we make regarding the components to include or exclude in our conceptions of SL, will make on the public. In my next chapter I will touch on one of these important questions, addressing empirically the conceptions active scientists and teachers hold about what it means to be scientifically literate, and whether this aligns with the domain-specific conceptions in the literature.

Figures

Figure 1 – The intersection of science and literacy

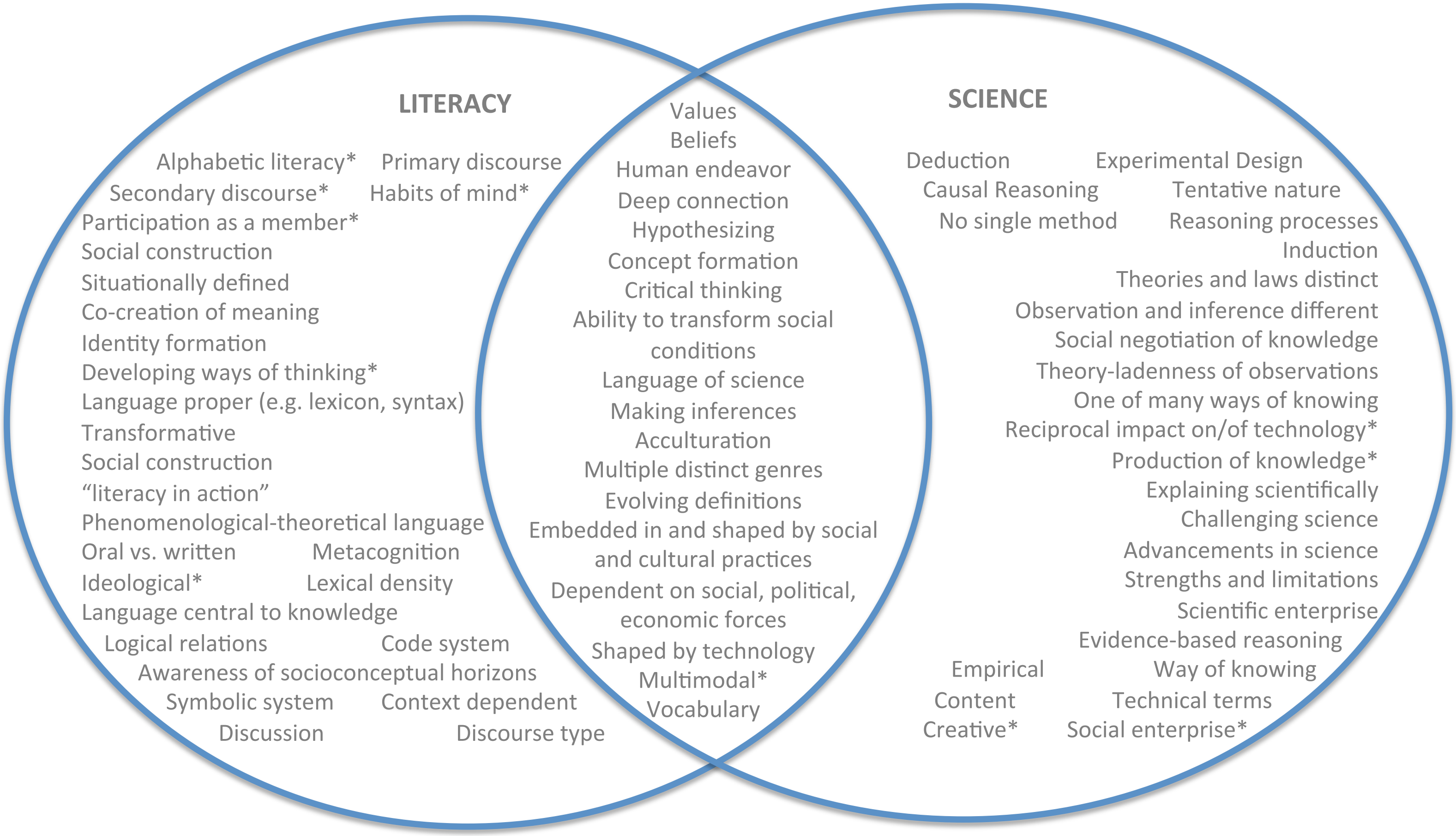
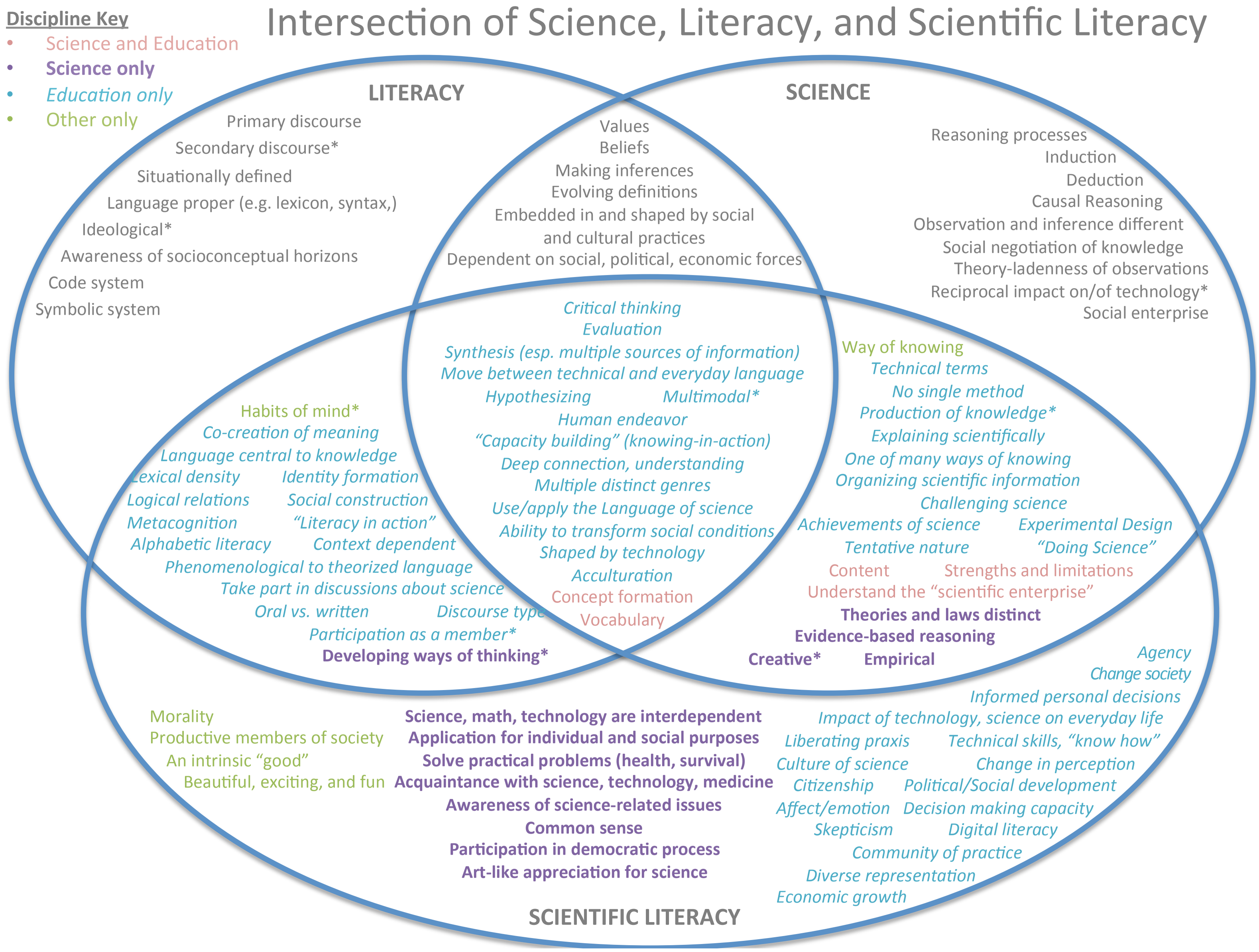
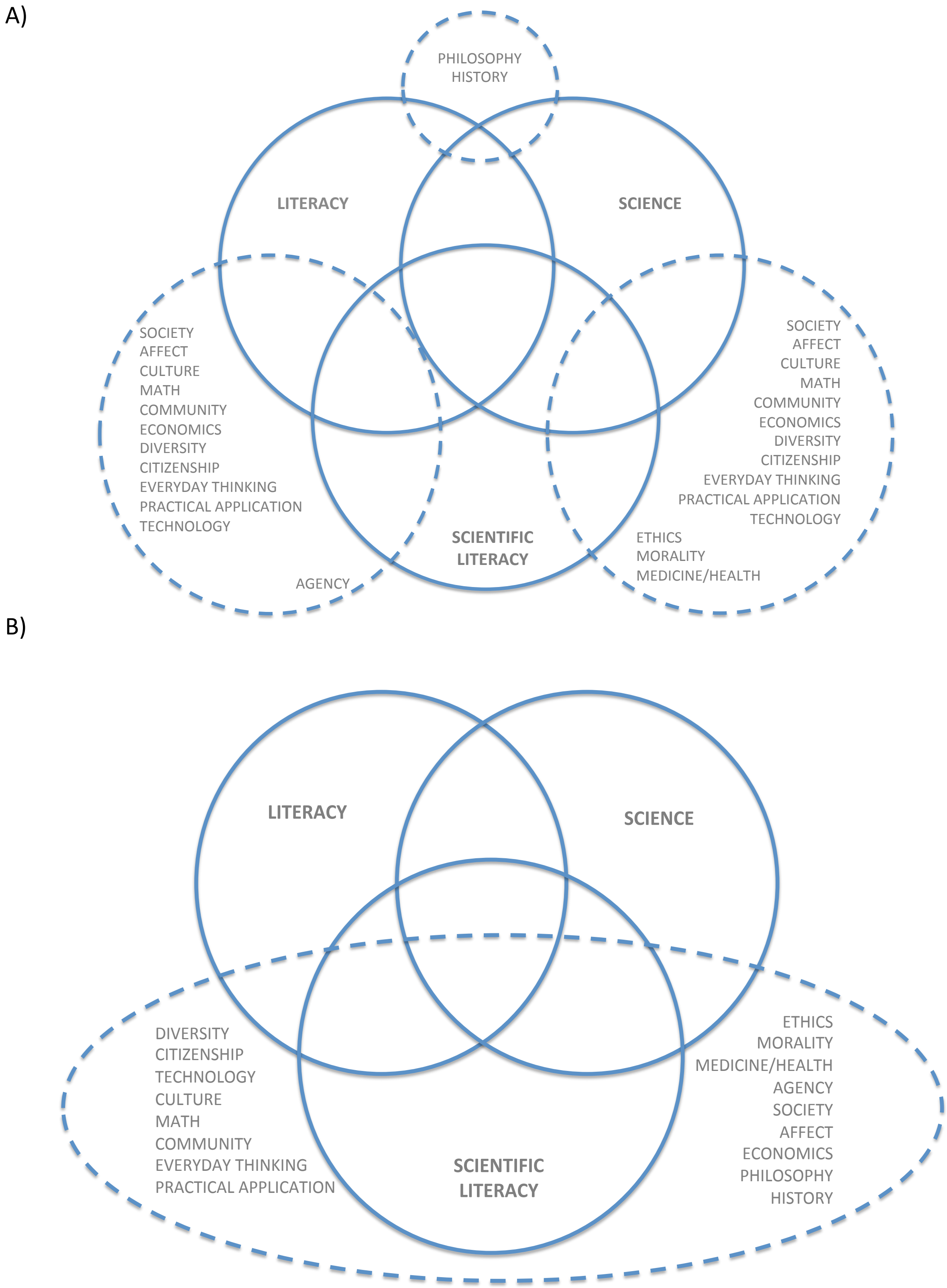


Figure 2 – The intersection of science, literacy, and scientific literacy, by discipline



*Key: * signify elements that could apply to both science and literacy, but were not supported in the literature*

Figure 3 – A potential landscape of linkages between science, literacy, and scientific literacy



CHAPTER 2 - CONCEPTIONS OF SCIENTIFIC LITERACY IN SCIENCE AND SCIENCE EDUCATION GRADUATE STUDENTS

It is clear that there are myriad conceptions of scientific literacy (SL) in the literature, but what has yet to be explored is how these conceptions align with the explicit or implicit definitions of practicing scientists and educators. While the theoretical definitions of SL may be rich, multi-dimensional, and polysemic this may not match the landscape of definitions held by the individuals at the interface of science and the public. How do these individuals define SL, and how does this translate to their interactions with the public? These are empirical questions, and yet in the almost seven decades since the inception of the term, in Hurd's influential 1958 paper, there have been only a handful of empirical studies that focus on the ideas and definitions of SL that are used in practice, or *practical* definitions. Of these publications, almost half do not have enough information about the study methods or results to be utilized in any meaningful way (e.g. Carlton, 1963; Champagne & Lovitts, 1989). Further, no study questions participants' conceptions of science and literacy to understand the natural intersection of the two in practice, and how these might interact to result in SL.

This chapter investigates the conceptions of SL for two groups that regularly communicate with the public about science: graduate students in the sciences and in science education. Graduate students are poised to make a large impact on public understanding of science as these individuals regularly communicate with the public about science both formally and informally, as teaching assistants in their universities, through public outreach and by informal dissemination of information to the public. This means that the ideas that these individuals hold about SL could have a disproportionate impact on the public perception of science and must therefore be examined. Most importantly, as these individuals are still immersed in a learning environment they are exposed to the current educational paradigms, forming a more homogenous group in experience and exposure to the most recent educational reform. In contrast, other researchers and educators in the sciences, such as faculty and teachers within the formal educational system, would have a wide range of exposure to the various educational reforms in the seven decades since the inception of the term (see Chapter 1; DeBoer, 2000). This study will therefore shed light not only on the relationship between the theoretical typology and practical definitions, but also the impact of the most recent educational reform on conceptions of SL.

Chapter 1 focuses on the landscape of SL definitions in the literature base, resulting in a theoretical typology of components. The current chapter focuses on applying this typology to practical definitions of SL. This is done through an open-ended survey that elicits graduate students' implicit conceptions of SL, when applied to a typical outreach activity (a blog post), as well as their explicit definitions of science, literacy, SL, and the intersections between them. These responses are compared with the theoretical typology as well as the set of relevant literature base to determine the amount of overlap between theoretical and practical definitions of SL. This is an important step towards understanding the impact of individuals' practical conceptions of SL on public understanding of science and whether the theoretical typology of SL definitions can predict individual, practical conceptions of SL.

Literature Review: Practical Definitions of SL

Search Methods

Empirical studies on individuals' conceptions of SL are rarely mentioned in the general SL literature, so a more extensive literature search was necessary. Because so few relevant publications were found overall, the search methods are explained in detail. The first phase included several iterations of key word searches in google scholar, including: graduate student "scien* literacy" empirical; Conception "scien* literacy"; "scien* literacy" survey defin*. Each set of terms was searched until there were several pages with no hits, and for at least ten pages total. The second phase utilized the citations in the relevant papers, as well as some references to relevant papers in tangential papers, to find more publications. In the third phase each relevant publication was tracked, using Google Scholar and ISI Web of Knowledge, for other publications citing those studies. This was done for each new relevant publication found; the second two phases were repeated until no new publications were uncovered.

Excluded Literature

There are several publications closely aligned with eliciting a definition of SL, but instead ask what it means to "study something scientifically" (Davis, 1958; Impey, Buxner, Antonellis, Johnson, & King, 2011; Miller 1980, 1989, 1995, 1998, 2004, 2010). While this is similar to asking about the definition of SL, the intention of this was expanded on in Miller (1989) as the "process of theory formulation and testing" (p. 7) and was under the header of "understanding the process of science". Therefore, this was presumed to be a measure of individuals' conceptions of nature of science, rather than scientific literacy as a whole. Additionally, this was not eliciting a definition or objective of SL (what it *is*; its *aim* or *goal*) and would have been difficult to compare to the literature in Chapter 1, had it been more aligned with SL. Therefore these publications were excluded from the relevant literature. This left six total relevant publications exploring individuals' conception of either the definition or objectives of SL.

Survey of the Relevant Literature

While there are very few publications overall on this topic, especially given the bounty of publications on SL in general, there are a few high quality empirical studies of the conceptions of SL for university science educators, individuals from universities and the public, science and non-science oriented individuals, administrators, teachers, and scientists. However, there are just as many for which individuals' conceptions of SL are simply a passing reference (Champagne & Lovitts, 1989) or a very short and ambiguous section (Jordan, Grey, & Duncan, 2008). Therefore, the relevant literature is divided into two sections, *partial reference* and *complete reference*, to delineate the studies that did not provide enough information in their methods or results to compare meaningfully to future studies with those that can be compared or replicated. Because the list of relevant literature is so short I felt it important to mention even these partial references to the practical definition of SL, as these can still provide some insight into non-theoretical conceptions of SL.

Partial reference. Champagne & Lovitts (1989) made a brief reference to an informal study conducted by the American Association for the Advancement of Science (AAAS), but without reference to the study itself or who the participants were. They summarize that the AAAS study provided "respondents" with 15 items about "capabilities and attitudes" and rated, on a fixed scale, the importance of these "to scientifically literate high school graduates". Only the top and lowest rated were reported on, with the highest rated being "read-and-discuss abilities" (the ability to function in the workplace and make informed personal and civic decisions) and the lowest "define, describe, and design" (representative of typical questions asked in a school setting) (p. 5). The authors deduce that while these low-rated “academic abilities” are an important foundation of the read-and-discuss abilities, they are only relevant if they can be applied to practical situations (p. 6). While this is an interesting insight into the relative importance of some factors of SL, this is not a meaningful contribution if we cannot parse out who was asked, when they were asked, or what questions were included in the survey.

Jordan et al. (2008) included some relevant information about their pilot study, but still not enough to be compared to or replicated in future studies. The section reporting on science teachers’ definitions of scientific literacy was very short and did not specify what question type was asked, and whether it was closed- or open-ended. Further, the results were generalized and summarized to the point that it would no longer be meaningful to compare these results to those from another study, except perhaps for their interpretation of some of these definitions as pragmatic and others as focused on content. However, it is worth noting that a large portion of participants were unable to provide any definition of SL when explicitly asked.

> When asked to define scientific literacy, six teachers provided pragmatic definitions about being able to write or interpret scientific information, five teachers equated literacy with understanding facts or vocabulary, four reported that they did not know, and one gave no reply. These responses regard literacy as the ability to interpret and understand information, which are requisite for scholarship. (p. 38)

Carlton (1963) asked highly esteemed scientists and science educators what SL meant to them, with questions like: “What does it mean to be scientifically literate? How can you raise the level of your scientific literacy? And why is it important that all teachers, along with other intelligent adults, be scientifically literate in today's world?” (p. 33). However, this was a short article without a methods section or a full list of questions, and truncated participant responses. While selecting certain quotations from participants to support an argument or contextualize an analysis is an acceptable practice, these answers were “selected and abstracted to present a wide range of ideas and suggestions” (p. 33). As these were not systematically chosen or representative of what was said this article cannot be used for future analysis. At best, then, these definitions can provide a general impression of the diversity of conceptions at the time regarding SL, such as DeBoer’s (2000) analysis: “most focused on greater content knowledge in a broad range of science fields; only a few spoke of the relationship between science and society" (p. 587).

Complete reference. Kemp's dissertation (2002) provides a comprehensive interpretive analysis of university science educators' conceptions of the goals of SL (n=9). Almost all are well known in or very invested in the SL field, generally sharing that they are "internationally recognized for promoting the goal of scientific literacy" (p. 104). While this is an incredibly informative study, it only partially aligns with the focus of this study in that while these are individual conceptions of SL, given that these are the same individuals *developing* the theory, their "practical" responses may not be easily separated from their "theoretical" responses (or what I call quasi-theoretical responses). Nevertheless, this provides an interesting insight into the difference between the comprehensive array of theoretical definitions in the literature and the conceptions of individuals in the field in a non-academic setting. This is an especially informative study because of the breadth and focus of the interviews, with 20 guiding questions (though due to the semi-structured nature not all were asked in any one interview) about the goals of SL, the characteristics of a scientifically literate and illiterate person, how one becomes SL, and their opinions about some of the SL literature. Finally, they were asked to reflect on their responses and explicitly define SL. The interview transcripts were coded for elements of SL and then clustered into three dimensions: Conceptual, Procedural, and Affective. The Conceptual dimension "includes those things that can be classified as knowledge or understandings"; the Procedural dimension involves "procedures, processes, skills, and abilities that the participants think are attributes of the scientifically literate"; the Affective dimension includes "a range of attributes connected to emotions, such as feelings, attitudes, values, and dispositions" (Kemp, 2002, p. 125). The elements included in each of these dimensions can be found in Figure 4. Kemp found that even these scholars in the field focused on a subset of elements from one or two dimensions as most important, with a few different common emphases: conceptual and affective; conceptual and procedural; procedural; procedural and affective (p. 127). In Figure 5 it can be seen that by far the major emphasis is Procedural, followed by Conceptual. The Affective dimension was only really emphasized by one individual. While there were some elements within each dimension that were more commonly "endorsed", this consensus doesn't reflect the divergence of views even about these elements (Figure 6; p. 203). Kemp concludes that there is more divergence than consensus and that "this diversity of views is (or has the potential to be) hindering efforts to improve the teaching and learning of science in the United States." (p. 253).

Brickhouse, Ebert-May, and Wier (1989) held a round table discussion with a mix of administrators, teachers, chemists, and pre-service teachers about what it means to be scientifically literate, moderated by a staff member from the American Association for the Advancement of Science (AAAS). Many of these participants were leaders in science education, but unlike Kemp (2002) they were not recognized for their contribution to or expertise on SL or *all* experts, but this still may represent a theoretical understanding of the topic from some

Table 4 - Brickhouse et al. (1989), Table 1

Category "Sample Remark"	Admins	Teachers	Students	Scientists
Science, Technology, and Decisions " ... there are environmental decisions that have to be made, nuclear decisions that have to be made.... "	High	High	High	High
Scientific Skills " ... I want my students to understand and be able to perform the scientific processes of observation, making hypotheses, testing hypotheses, drawing conclusions, and making inferences."	High	High	Low	High
Everyday Coping "ability to function in the modern world."	High	High	High	Low
Correct Explanations "You have to know the basic laws of science and you have to know some facts about the subject you're going to talk about before you can come anywhere near doing most of the other things."	Low	High	High	Low
Appreciation of Science " ... the excitement and the enthusiasm for knowledge that these children have which is certainly one part of what you want to have in scientific literacy"	None	Low	High	High

Table 4 (cont.)

Structure of Science "We [scientists] try to come up with ideas that tie everything together but they're always inadequate. Any kind of scientific theory is not a completely accurate description of the world. We refine things as we get more evidence and more sophisticated theories."	Low	None	Low	High
Solid Foundation "Learning should be a progressive thing where knowledge is built on knowledge from one grade, where one grade has to prepare you for the next grade in science, and so on.... "	Low	None	Low	Low
Self-As-Explainer "...uses and processes of science as opposed to religion and magic."	Low	Low	None	None

Note: Replicate of Brickhouse et al. (1989) Table 1: Ranking of Categories of Scientific Literacy by Administrators, Teachers, Students, and Scientists (pp. 160-161) "*The terms "High," ''Low," and "None" represent the relative importance of the category indicated by each group. The relative importance was gauged by observing the percentage of individuals in each group who made statements pertaining to the category. High: No. >/= 50%; Low: 0 < No. < 50%; None: No. = O."*

highly invested individuals. Responses were analyzed by top-down application of eight categories from Roberts (as cited in Brickhouse et al., 1989[7]). The relative importance of each category (measured by how frequently it was mentioned in participant responses) was compared across groups and summarized in Table 4, which replicates the table from Brickhouse et al. (1989). This table follows the overall ranking of categories across all groups, with "science, technology, decisions" most important and "self as explainer" least important. There were a number of differences by group; teachers and administrators were most similar in response, and scientists were the most divergent from all other groups. The students had the most difficulty articulating arguments about SL, which Brickhouse et al. (1989) concludes is due to their "status as novices" (p. 174). Aligning with their respective professional foci, scientists focused more on the discipline of science and administrators were concentrated on the application of these ideas to the community, and accountability for learning these skills.

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[7] No citation was provided in the Brickhouse et al. (1989) to the Roberts 1983 publication

Gabel (1976) used the theoretical literature base to create a theoretical definition of SL, with several dimensions. He provided a large and diverse sample of individuals with these dimensions and had them rate their agreement with each of 45 statements. This was used to infer a definition of SL from science and non-science oriented individuals, and for the combination of the two, as well as to compare the responses of the two groups and their subgroups. Participants included university pure science (N=37), university applied science (N=38), university nonscience (N=75), public science (N=100), public nonscience (N=100). This resulted in seven inferred dimensions of SL, along with one stemming from science-oriented and one dimension from nonscience-oriented individuals (Table 5).

Table 5 – Inferred Dimensions of SL, Gabel (1976)

Group	**Inferred Dimension**	**Definition**
Both	Scientific Inquiry	Producing new knowledge through a synthesizing type of activity
Both	Maintaining current awareness	Valuing of people keeping touch with and maintaining an understanding of new developments in science and technology
Both	Valuing methods of science	Personal valuing of methods which scientists use in their work
Both	Personal application of science	Application of scientific knowledge and methods of science in daily living
Both	Distinguishing between science and technology	Distinguishing between science and technology in terms of goals and results
Both	Utilizing factual knowledge	Knowing and using for various purposes factual knowledge about nature
Both	Mutual involvement of science and society	Society examining its values as science provides mankind with more capabilities. Also, society should establish conditions within which science can thrive
Science	Science as a human endeavor	Playing down the "omnipotency" of science, technology, and scientists
Nonscience	Using natural resources	The scientifically literate person using his knowledge to judge decisions made with regard to aspects of nature

While there were some differences in the dimensions valued by those with science experience versus those without formal science experience, there were more differences within each of these groups, as can be seen in Table 6. In both the science oriented groups (university applied and pure science, and public science) and nonscience-oriented groups (university and public nonscience) there are some categories that are highly valued by one sub-group and valued less by others. Additionally, there are many categories that are only valued by one of the sub-groups. Gabel (1976) found that demographic factors did impact perception of SL, with the least educated in the public valuing more practical aspects of SL. Finally, there were many components in the theoretical definitions of SL that did not emerge from this analysis, and this may result in different perspectives for the "layman" and science educators (p. 254). As this study was conducted over four decades ago this may no longer be representative of public opinion, especially given the significant shifts in social and educational paradigms in this time. Therefore it is imperative that these results be followed up with further studies to understand the implications of contrasting perspectives on SL for public understanding of science.

Table 6 – Visualization of Participant Groups and SL Categories, from Gabel (1976) Text

	methods	science vs. tech.	personal involvement	factual knowledge	current knowledge	science & society
University Pure Science	x	x	S			
University Applied Science			o	x		
Public Science		o	x		x	
University Nonscience					o	o
Public Nonscience				x	x	

Note: x = high value, o = value less, S = split response (individuals in physical science value this less, and in life/earth science highly value it). Nonscience, both University and Public, are shaded.

Conclusions. In conclusion, while there are only three relevant publications that provide sufficient information to contribute meaningfully to the topic, one of these does not even align with the focus on practical definitions of SL. Even so, these quasi-theoretical notions of SL will be informative for comparison with the current study. All of the relevant publications provide some insight into the practical notions of SL, but there are many gaps to address. Most importantly, no study asked participants to define science or literacy to understand the natural intersections between the two that might result in a practical (or quasi-theoretical) conception of SL. This natural intersection will be investigated in the current study, along with the commonalities and divergences between the theoretical SL components and the notions individuals hold about SL in practice.

Methods

Participants

Selection criteria and recruitment. Participants were recruited through social media, university list-serves, and fliers using IRB-approved recruitment scripts (see Appendix C for full scripts). Because of the large reach of social media, graduate students from any university within the United States could participate. Participation was restricted to graduate students in the sciences, science education, or closely aligned fields such as philosophy of science.

Demographics. The first component of the survey was a demographic form, asking for gender, ethnicity, and race, along with their university, department, and focus. To contextualize participant responses in the main survey questions, they were also asked for: the number of years in their current position; the number of years experience with science and a short description of what that description entailed; their experience with outreach and a short description of that experience. Experience with outreach was broken into five categories: very little experience, some experience, some independent experience, significant independent experience, and expert-level experience. The descriptions were used to corroborate the category choices. Finally, they were asked to describe their typical audience and their motivation for science outreach to get a more complete idea of how invested they are in outreach, as an indicator of their experience with the theoretical aspects of SL.

Survey

Questions and rationale. The survey included six total open-ended responses, based on participant opinion and experience (see Appendix C for full survey). The first question asked participants to outline a blog post with the title "What you should know about science" to elicit their implicit conceptions about scientific literacy through what they think the public should know about science. Question two asked participants to explain who this "public" is and what they may already know about science to contextualize their implicit notion of SL. Questions three, four, and six asked for their explicit definition of SL, science and literacy, respectively. To better understand the intersection between science and SL, as well as literacy and SL, questions five and seven asked the participant to compare SL to science and then to literacy, respectively. Questions three through seven allowed for explicit evaluations of the natural intersection of SL, science, and literacy, to compare to the theoretical intersections. The first two questions provided a space to apply their intuitive or explicit conceptions of SL to a real-life scenario, for a richer comparison of theoretical to practical definitions of SL.

Collection technique. Interested participants were provided with a link to a University affiliated web-based survey platform. Drafts were not reported to the author; surveys were only logged when the participant elected to submit the entire survey. The anonymized results were downloaded and viewed after the survey had closed and no more drafts could be submitted.

Duration. There was no time restriction on how long or over how many sessions participants could complete the survey, however it was intended to take no longer than one hour total to complete. Because of the autonomy of a web-based survey, participants were given the opportunity to complete the survey at any time over the four week time period, and time taken to complete the survey was not tracked or controlled for.

Confidentiality. Participant responses were dissociated from any identifying information, such as name or email, through the survey platform. The author had no access to this information. Responses were then coded with a participant number for further anonymity. Participants were made aware of their rights to confidentiality in the IRB approved consent form (Appendix C), which had to be electronically signed before moving on to the survey.

Quantitative Analyses

Demographic correlations. The correlation between year in the program (Years Position), years experience with science (Years Science) and experience level with outreach (Outreach Experience) was calculated using Pearson Product-Moment Correlation Coefficient (*r*). The correlation was calculated for: Years Position and Years Science; Years Position and Outreach Experience; Years Science and Outreach Experience. A *t*-test was used to determine significance (α=0.05, two-tailed).

Correlation between demographics and SL components. The Pearson Product-Moment Correlation Coefficient (*r*) was calculated for each of the aforementioned demographic factors, paired with each of the four measures for the number of SL components included in participants' responses. SL Total represents the total number of components included - explicitly, implicitly, or as a comparison – in a participant's response that characterize scientific literacy. SL Explicit only includes components from the explicit definition of SL. Similarly, Science Explicit includes only components from the explicit definition of science, and Science Total widens the components included to explicit, implicit, and comparison questions. Figure 7 outlines the entire set of comparisons. The first box means that a correlation was calculated for: Outreach Experience and SL Total; Outreach Experience and SL Explicit; Outreach Experience and Science Total; Outreach Experience and Science Explicit. This was done for all three demographic factors. A *t*-test was used to determine significance (α=0.05, two-tailed).

Qualitative Analyses

Theoretical SL components in complete, relevant studies. Each of the three complete, relevant studies were analyzed for the inclusion of the theoretical SL components in the typology from chapter one (see Chapter 1, Table 3). To the extend possible, all responses, regardless of how they were grouped in their original analyses, or in later discussion, were included in my analysis. Because of the differences in methodology and reporting, with different levels and depth of information about participant groups, individual responses, and category explanation and examples, grouping all responses regardless of original categorization was the most parsimonious method of analysis. While this does reduce some of the complexity of participant responses, this provides an overall picture of what was found in each study and how the prior literature aligns with participant response in the current study.

Theoretical SL components in current study. The seven main survey questions (excluding the demographic information) were analyzed using the same top-down analysis as for the relevant studies, using the SL component typology. All nine participant responses were mapped onto the typology of theoretical SL components individually, and then the science-focused individuals (n=8) were combined to be compared with past studies. The one science education focused individual was excluded from this summary table, but response analysis can be found in Appendix F. Each participant was coded individually, with each idea (element) mapped onto one or more appropriate components in the typology. Examples of these elements can be found in Table 7. If applicable, a range of responses was provided for multi-faceted components (with many sub-components). As there are no example quotations for the component relationship to technology (under Linking Dimensions), it should be noted that this is solely a link between science and technology, not the social implications that fall under science technology and society. As all participants intertwined technology with social implications these elements were only coded under science technology and society, and none fell under relationship to technology.

Table 7 – Analysis of theoretical SL components in current study, example quotations

Super-Component	Component	Example Quotes
Foundational Literacy	Primary Discourse	Literacy is competence, the ability to understand the words and tools of a specific discipline or language (P2)
Scientific Enterprise - Surface	Content	They would have to be able to read basic science or understand what science is and have an understanding of what each of the branches of science were (P3) [science is] The accumulation of theories that seek to understand/explain the world around us. (P4)
	Terminology	[SL only requires to] be familiar with the terms (P3)
	Reasoning processes	Scientists need to be able to critically evaluate studies, be able to replicate them to apply it to their research. (P3) Science is the inquiry-based approach to acquiring and organizing knowledge about the world around us (P5)
	Knowledge production	...how that, in basic terms, has added to general human knowledge. (P3)
	Language of science	To be literate in science, in my opinion, is to have proficiency or understanding what is being talked about, as a baseline (P8) Science literacy is a subset within [science] involving the skill to communicate about science (P5)

Table 7 (cont.)

	Genres of science	It means they know the scientific process (P1) There are standard ways we have done science (P3) ...through data collection, including collection of observations, experimentation, and theoretical development (P2)
Scientific Enterprise – Deep	Nature of science (pragmatic)	How to identify good science from junk science (P1) You can't prove a theory (P2)
	A way of knowing	N/A
	Sociality is central to meaning	Describe granting process, conflict of interest regulations at universities, and also how peer review can stop COI (P2)
	Never autonomous or neutral	What role does objectivity play in science? (objectivity is a goal, but not a guarantee, in science, because scientists are people too, this is why we have peer review) (P2) Science is not black-and-white. There is more than one way to interpret results. Scientists are people too. We have feelings and we make mistakes. (P4)
Linking Dimensions	History of science	Draw parallels with what science has done poorly (e.g., atoms bombs, war) and what has been done well (e.g., medicine) (P8)
	Aesthetic qualities	If you would like to learn more, listen in your science classes, take a science class, read a book, or watch YouTube videos about topics that interest you! Science is out there waiting for you to learn about it! (P3)
	Connection to other domains	Science is not a faith in its own right, a threat to or a replacement for religious belief (P6) Health I believe people need to have at least a basic understanding of biology to understand their own bodies and how they work and how they can fail (P7)
	Relationship to technology	N/A
Pragmatics	Impact on decision making in everyday life	Importance of science – necessary for making educated decisions (P7) It is not an understanding of complex or very specific topics in science, it is simply that someone can understand enough to ask questions after being exposed to some scientific topic and can ask questions after to know more (P8)
	Science, technology, and society	Oftentimes, the questions that a scientist seeks to answer present themselves in the form of social problems (P6)

Table 7 (cont.)

Critical Dimensions	Centrality of language and discourse	How material is presented certainly can affect an individual's scientific literacy. For example, a scientist doubling as pop sci writers often have a knack for making a complex topic more digestible (P5)
	Transformational	Advance human interests. Increase quality of life (P1) Each discovery gives us insight into ourselves (P8)
	Deep connection and/or understanding	Science can be done by anyone who employs the scientific method, but scientific literacy is a skill that must be learned/taught (P4)
Expert-Level	Philosophy of science (broad)	N/A

Ideas relating to SL, science, and literacy were coded separately, but all on the same typology to compare their intersections. Explicit definitions, implicit definitions, and comparisons were differentiated in initial coding, and any response that did not include at least one explicit idea was coded differently in the included tables and figures. Full responses to the question in which participants were asked to explicitly define SL are included in Appendix E.

Comparison of theoretical SL components in current and past studies. The number and type of theoretical SL components included in current and past studies (including both complete and partial, relevant studies) were compared for holistic differences. Quasi-theoretical definitions from Kemp (2002) are also discussed in relation to the practical definitions in complete, relevant studies and the current study.

Overlap of science and literacy in current study. Similar to the theoretical overlap of SL, science, and literacy from Chapter 1, each idea (element) of participants' responses was included in a Venn Diagram (Figure 13) to understand the natural overlap of these elements of SL. This diagram represents the amalgam of all participant ideas, so even if an element was present in the explicit science definition for one individual and in the explicit SL definition for another, it would be placed in the intersection between science and SL. Repeated elements were only included once. While there was only one individual outside of the sciences, these ideas were mapped onto the Venn Diagram using a different color to represent potential disciplinary differences. Elements only found in responses from science graduate students are shown in purple, elements only from the science education graduate student are in blue italics, and responses from both disciplines are in pink.

Natural intersection of science and literacy, theoretical versus practical. The natural intersections of SL, science, and literacy were compared for the theoretical Venn Diagram (Figure 2) and the practical Venn Diagram (Figure 13) for holistic, qualitative differences in the number of elements, types of elements, and what fields and intersections are most populated.

Results

Demographics

Participant demographic information is summarized in Table 8, with the exception of ethnicity and race as all participants selected Non-Hispanic, White. Of the nine total participants, five were female and four were male. There was a large range of disciplines represented in the study, including environmental studies (NRES), anthropology, chemistry,

Table 8: Demographic Information Summary

ID	Gender	University	Department	Focus	Years Position	Years Science	Outreach Experience[b]
P1	Male	Large R1-A	NRES[a]	Science	3	10	*****
P2	Female	Large R1-A	NRES	Science	3	8	****
P3	Female	Large R1-A	Anthropology	Science	5	15+	***
P4	Female	Large R1-B	Chemistry	Science	5	11	***
P5	Male	Large R1-A	Entomology	Science	3	14	**
P6	Male	Large R1-A	Plant Biology	Science	5	10	*****
P7	Female	Large R1-A	-	Science	1	13	***
P8	Male	Large R1-A	Entomology	Science	1	5	****
P9	Female	Large R1-A	Curriculum and Instruction	Science Education	4	15+	****

*Notes: a - Natural Resources and Environmental Sciences, b - asterisks represent the selected experience with outreach *=very little, **=some, ***=some independent, ****=significant independent, *****=expert-level* entomology, plant biology and education (Curriculum and Instruction). The majority (n=8) were focused on science in their graduate degrees, with one focused on science education (n=1). There was a range of experience with science (Years Science), but no participant had less than five years and most (n=7) had ten or more years of experience (Figure 8). All but one participant were from the same university, and all were in large research oriented (R1) universities in the United States. There was a large range of years that the participants have been in their current position (Years Position), with some in their first year and some in their fifth year (Figure 9), representative of a typical range of years individuals will remain in graduate school. Finally, there was a range of outreach experience (Figure 10) that spanned the categories in the survey, from some experience to expert-level experience. No participant selected very little experience, which is to be expected given the self-selective nature of this survey.

Quantitative Analysis

Demographic correlations. There was a moderate positive linear correlation between Years Position and Years Science (r=0.405, t=1.172; Figure 11) and a very weak correlation between Years Position and Outreach Experience (r=0.010, t=0.026) as well as Years Science and Outreach Experience (r=-0.023, t=-0.061). As all t-values are below t^{crit}=2.365 we fail to reject H_o: ρ=0 and conclude there are no significant linear relationships between Years Position, Years Science, and Outreach Experience.

Correlation between demographics and SL components analysis results. There was a moderate negative linear correlation between the number of theoretical SL components included in the question explicitly asking for the definition of SL (SL Explicit) and the individuals' outreach experience (r=-0.435, t=-1.276; Figure 12) and weak correlation for all iterations of the demographics and SL Total, Science Total, and Science Explicit ($r<|0.337|$, $t<|0.947|$; Table 9). As all t-values are below t^{crit}=2.365 we fail to reject H_o: ρ=0 and conclude there are no significant linear relationships between the three demographic factors and the number of SL components included in participant response.

Table 9 – Summary of Quantitative Analysis for SL Components and Demographics

Analysis Type	Outreach Experience	Years Science	Years Position
SL Total	-0.031 (-0.082)	-0.173 (-0.464)	-0.051 (-0.136)
SL Explicit	-0.434 (-1.276)	0.076 (0.202)	0.077 (0.204)
Science Total	0.029 (0.076)	-0.217 (-0.589)	-0.238 (-0.649)
Science Explicit	0.159 (0.426)	-0.102 (-0.272)	0.337 (0.947)

Note: Values are reported as r (t)

Qualitative Analyses

Theoretical SL components in complete, relevant studies. Aligning with the description of the theoretical typology from Chapter 1, while not all components from each super-component were present in the responses from each of these studies, no super-component was skipped, with at least one component populated in each category leading up to the final super-component, which in all studies was Pragmatics (see Table 10). The most highly populated super-component was Scientific Enterprise-Surface. There were very few components within the Scientific Enterprise-Deep super-component, with science-oriented individuals contributing the second component populated in Gabel's study. Similar to the conclusions drawn by Gabel (1976) in all three studies there is a focus on the practical application of science, and this includes a solid foundation in content knowledge and other surface-level components of the scientific enterprise. This also aligns with the findings from Jordan et al. (2008), in which teachers were focused on pragmatics, and Champagne et al. (1989) in which the surface-level components were only relevant if they could be applied.

It is unsurprising that, overall, the highest number of components were included in definitions from experts in the field of scientific literacy (Kemp, 2002; 12), then the intermediate number from those well versed in science education in general (Brickhouse et al., 1989; 9), and the least from those outside of the science education community, or even the sciences in general (Gabel, 1976; 8). However, these trends have to be interpreted with a grain of salt due to the interpretive nature of assigning distilled representations of rich responses to fixed categories. Yet, it is noteworthy that this trend matches the intuitive, expected pattern. This trend could be explained equally well by a shift in educational paradigms over time, and the resultant snowball effect of including more and more components into the umbrella term "scientific literacy", as discussed in Chapter 1 (see DeBoer, 2000, p. 594).

Table 10 – Analysis of theoretical SL components in complete, relevant studies

Super-Component	Component	Kemp 2002	Brickhouse et al. 1989^	Gabel 1976
Foundational Literacy	Primary Discourse			
Scientific Enterprise - Surface	Content	x	x	x
	Terminology	x	x	
	Reasoning processes	x	x	x
	Knowledge production		**F**	x
	Language of science	x	x	
	Genres of science	x	x	x
Scientific Enterprise – Deep	Nature of science (pragmatic)	x	x	
	A way of knowing			
	Sociality is central to meaning			x
	Never autonomous or neutral			**S**
Linking Dimensions	History of science	x		
	Aesthetic qualities	x	x	
	Connection to other domains	x		x
	Relationship to technology	x		
Pragmatics	Impact on decision making in everyday life	x	x	x
	Science, technology, and society	x	x	
Critical Dimensions	Centrality of language and discourse			
	Transformational			
	Deep connection and/or understanding			

Table 10 (cont.)

Expert-Level	Philosophy of science (broad)			
OTHER*	Using natural resources			**N**
	Maintaining current awareness			x
Total Components		**12**	**9**	**8**

*Notes: * = categories not aligning with the theoretical SL components; ^ = Solid Foundation and Self-As-Explainer are not included because they were not a focus of any discussion; F = discussed in their framework for analysis, but not obviously mentioned by participants; S = inferred from science oriented participants only; N = inferred from nonscience oriented participants only*

There are two categories that did not completely align with the theoretical typology: ”using natural resources” and “maintaining current awareness”, both from Gabel (1976). Using natural resources is defined as: “the scientifically literate person using his knowledge to judge decisions made with regard to aspects of nature” (p. 242). While this does overlap somewhat with Pragmatics, the element of judgment is a new dimension, beyond that of application. Maintaining current awareness means: “valuing of people keeping touch with and maintaining an understanding of new developments in science and technology” (p. 240). While this is quite closely aligned with the content of science, there is again another dimension beyond simply knowing information to *valuing* this knowledge and *maintaining* it even with new advancements.

While there were some novel components not included in the theoretical typology, there were many more theoretical components not included in the studies. Similarly, Gabel found that there were many components in the theoretical definitions of SL that did not emerge from his analysis (1976, p. 254). It is unsurprising that the expert-level NOS was not mentioned, given that these components are not necessary for even scientists to be successful in their discipline. What was surprising is that there were no mention of the Critical Dimensions, as these play an important role in one’s everyday life. While Pragmatics touch on the impact science has on one’s everyday life, this is a transient or surface-level impact whereas the Critical Dimensions encompass the transformational, and therefore longer lasting, impacts of science. Most interesting is the lack of any mention of the necessity of foundational literacy, even from experts in SL. Perhaps a remnant of this can be found in the *language of science* component, but given the centrality of literacy to SL, this seems like a gap worth exploring further.

Theoretical SL components in current study. Similar to the complete, relevant studies in definitions of scientific literacy there was at least one component mentioned in each category through the final super-component, in this case the Critical Dimensions, in the consensus table for all science-focused graduate students (Table 11). While this held for this coarser-grain analysis, at the individual level this hierarchy was not supported, with no apparent trend as to which super-components were excluded in any given individual response (see Appendix F). Almost all participants in the current study included some aspect of foundational literacy in their responses pertaining to SL (n=7) though only two included this essential component in their explicit definition of SL (see Appendix F). Unsurprisingly, in their definitions of literacy all participants included foundational literacy and some mentioned the language of science. While definitions of literacy are able to be mapped onto this typology, this is not representative of the

Table 11 - Analysis of theoretical SL components in current study

Super-Component	**Component**	**Scientific Literacy**	**Literacy**	**Science**
Foundational Literacy	Primary Discourse	**X**	**X**	
Scientific Enterprise - Surface	Content	**X**		**X**
	Terminology	*x*		
	Reasoning processes	**X**		**X**
	Knowledge production	**X**		**X**
	Language of science	**X**	**X**	
	Genres of science	**X**		**X**
Scientific Enterprise – Deep	Nature of science (pragmatic)	**X**		**X**
	A way of knowing			
	Sociality is central to meaning	**X**		*x*

Table 11 (cont.)

	Never autonomous or neutral	**X**	*x*
Linking Dimensions	History of science	*x*	*x*
	Aesthetic qualities	**X**	
	Connection to other domains	*x*	**X**
	Relationship to technology		
Pragmatics	Impact on decision making in everyday life	*x*	**X**
	Science, technology, and society	*x*	*x*
Critical Dimensions	Centrality of language and discourse	**X**	*x*
	Transformational	*x*	*x*
	Deep connection and/or understanding	*x*	
Expert-Level	Philosophy of science (broad)		

Note: **X** *= at least one explicit; x = only implicit or comparison. Science-focused individuals only (n=8).*

content or range of elements comprising these definitions. This, along with the natural intersections of literacy with SL, will be further explored in later sections. However, it is worth noting that even in this typology there is a clear delineation between literacy and science, with the language of science and foundational literacy excluded from science definitions, and all other components of the scientific enterprise missing from literacy definitions; science and literacy are perfectly complementary. Yet, even given the complementary nature of science and literacy, mapping perfectly onto SL, there are some components of SL that are not present in definitions of either science or literacy. Terminology, aesthetic qualities, and a deep connection/understanding are only found in definitions of SL. In contrast, all components of both literacy and science are present in definitions of SL. Similar to the previous studies, there were some novel components not included in the theoretical typology, but none that were sufficiently ubiquitous to warrant a new component. However, there were two surprising foci that were not as prevalent in the theoretical typology. There were a large number of references to *inquiry* and *process of science*. Both of these fall within pre-existing components (reasoning processes and genres of science, respectively) within the theoretical typology, but because of the large focus on these elements in participant responses these could conceivably be pulled into their own categories under the Scientific Enterprise-Surface super-component.

Comparison of theoretical SL components in current and past studies. As can be seen in Table 12, there are more total components and super-components included in definitions of SL in the current study than the three complete, relevant studies. There are two more super-components (for a total of six versus four) and six more components (a total of 18 versus 12) than the most populated relevant study, Kemp (2002). This large difference could be due to methodological differences, or – given the large time difference between the current study and the most recent prior study – a reflection of larger changes in how SL has been conceived over time. However, narrowing this down to components present only in the explicit definition of SL, this difference lessens with only one more super-component and one less component than Kemp (2002). In both cases Foundational Literacy is only included in definitions from the current study; this was included in the definitions of most participants (n=7) (Appendix F). However, it is possible that there are some connections to this super-component in relevant studies within the *language of science* component that was simply not expanded on in the publications. Given the sheer number of components included in the current study, it is unsurprising that there is only one component unique to the relevant studies that was not present in the current study, the relationship to technology. The relationship to technology, as discussed previously, is intimately connected to science technology and society, a simpler version disconnected from the impacts on society. Thus, the uniqueness of this component could be called into question. In contrast, there are many components that are unique to the current study, including primary discourse and all three Critical Dimensions, all of which are in super-components not included in the relevant literature.

There are several points of complete overlap across all four studies (n=4), as well as partial overlap among three of the studies (n=5). The components that are mentioned in all four studies are shaded in Table 12. These include: content, reasoning processes, genres of science, and impact on decision making in everyday life. These points of consensus all fall under the content and application of science.

Table 12 - Analysis of theoretical SL components in current and past studies

Super-Component	**Component**	**Current study**	**Kemp 2002**	**Brickhouse et al. 1989**	**Gabel 1976**
Foundational Literacy	Primary Discourse	**X**			
Scientific Enterprise - Surface	Content	**X**	x	x	x
	Terminology	x	x	x	
	Reasoning processes	**X**	x	x	x
	Knowledge production	**X**		**F**	x
	Language of science	**X**	x	x	
	Genres of science	**X**	x	x	x
Scientific Enterprise – Deep	Nature of science (pragmatic)	**X**	x	x	
	A way of knowing				
	Sociality is central to meaning	**X**			x
	Never autonomous or neutral	**X**			**S**
Linking Dimensions	History of science	x	x		
	Aesthetic qualities	**X**	x	x	
	Connection to other domains	x	x		x
	Relationship to technology		x		
Pragmatics	Impact on decision making in everyday life	x	x	x	x
	Science, technology, and society	x	x	x	
Critical Dimensions	Centrality of language and discourse	**X**			
	Transformational	x			
	Deep connection and/or understanding	x			

Table 12 (cont.)

Expert-Level	Philosophy of science (broad)				
Total Components		**18/11**	**12**	**9**	**8**

*Note: Components present in all studies are highlighted. Bold and upper-case **(X)** represents that at least one element comes from the explicit definition of SL in the current study. F = discussed in their framework for analysis, but not obviously mentioned by participants; S = inferred from science oriented participants only*

This focus on content and application of science is echoed in most relevant studies, both complete and partial. There is a large emphasis in Kemp's (2002) participant responses on the procedural dimension of SL (Figure 4), which defines what the SL person is able to do. The secondary focus is the conceptual dimension, which is what a person should know or understand, containing the content of science. Even though the commonly endorsed elements are not completely agreed upon, these still reinforce this focus on application and content (Figure 6). In Brickhouse et al. (1989) the three most frequent participant responses focus on the application of science (Table 4). The first category is "science, technology, and decisions", which is equivalent to science technology and society. The second category is "scientific skills", in which an individual is able to perform science, and finally "everyday coping" which is equivalent to impact on decision making in everyday life. The next most frequent participant response focuses on correct explanations. While there was no consensus from participants on the inferred SL dimensions in Gabel's dissertation (1976) there was a focus on the practical aspects of SL for those with less education in the public. This also holds true in the partial, relevant literature in which there is a focus on the content of science, but only as it applies to its application (Champagne & Lovitts, 1989; Jordan et al., 2008). There was a similar focus in my study on Pragmatics, with most individuals (n=6) mentioning at least one component within Pragmatics in their definitions. All participants included at least one component from the Scientific Enterprise-Surface, which includes the content of science, with five specifically mentioning the content component (Appendix F).

Surprisingly, the only holistic difference between the quasi-theoretical SL definitions in Kemp's study (2002) was perhaps more of an emphasis on the linking dimensions, when compared to other prior studies. Yet when compared to the current study these potentially theoretically-focused definitions have many fewer components and super-components included in their definitions. Most surprising is the lack of breadth of components included in the Scientific Enterprise-Deep in the quasi-theoretical definitions, given the centrality of nature of science to the scientific enterprise in the literature.

Overlap of Science and Literacy in Current Study. While there were some clear connections between science, literacy, and SL from the theoretical typology, this does not showcase the interaction and overlap of the different ideas and elements within each of those definitions. Mapping these elements onto their respective locations in a Venn Diagram of science, literacy, and SL allows for a richer analysis of the natural intersections of these three definitions. Figure 13 is a visual display of where each element of the practical SL definitions falls in relation to science, literacy, SL, and their intersections. Given the focus of this survey on SL, it is unsurprising that most elements fall in some way within SL - in SL, its intersection with science, literacy, or the intersection of all three. The majority of elements are found in the intersection of science and SL, with science containing almost as many elements as SL. Literacy has by far the fewest elements contained within, and there are very few in the intersection between SL, science, or both. There are several elements that are exclusive to each discipline, and this is expected given that there are components of science that are not necessary for the public to know, there are domains of literacy that are not necessary for one to be scientifically literate, and there are other domains (such as mathematics, politics) that intersect with SL besides science and literacy. There is a dearth of elements in the intersection of all three domains, two of the five total elements stemming from the science education focused individual. Other than this contribution, there are no apparent disciplinary differences between science and science education, but any trends would be difficult to support given the low sample size. For both disciplines, there are many components that are exclusive to SL, with no connection to either science or literacy. These presumably intersect with other related domains. Even after explicitly asked how literacy relates to SL, there are only a few elements in the intersection of SL and literacy. These elements are basic, representing foundational literacy skills (such as reading, writing, and recognizing meaning), and are not representative of the dynamic and complex definitions of literacy in the literature (see Chapter 1).

Natural intersection of science and literacy, theoretical versus practical. In contrast to the large focus on the scientific enterprise in the current study, there is a much more balanced contribution of science, literacy, and their intersections in the theoretical definitions of SL (Figure 2). There are also many more elements in the intersection of all three domains, as well as in the intersection of SL and literacy. However, this balance seems to stem from disciplinary differences. Definitions stemming from the sciences are more focused on the contribution of science to SL, with no meaningful contribution of literacy. Further, there are only two elements in the intersection of all three domains. The balance seems to come from the field of education, for which definitions are more integrative, including elements from literacy, science, and their intersections. In the theoretical definitions the literacy-based elements are much more representative of the breadth of literacy definitions found in the literature. The theoretical definitions have many more elements exclusive to SL; this could either represent a greater number of overlapping, related domains or a more extensive connection to the same number of overlapping domains. Given the diversity of elements it is more likely that this is due to a greater number of overlapping domains. Overall, there is a large, holistic difference between the distribution of elements in the theoretical and practical definitions of SL, with many more connections between science, literacy, SL, and other domains for a more balanced and integrative theoretical definition of SL.

Discussion and Conclusions

Discussion

While there are a plethora of theoretical SL definitions in the literature, there are very few studies that examine individuals' conceptions of SL in practice. Which of the many theoretical components, if any, individuals outside of the field of SL utilize in practice is an important empirical question addressed in this chapter. There are only a handful of studies that address this issue. While all relevant studies can provide some insight into these practical conceptions, only three have enough detail to be meaningfully compared to other studies. Of these three complete, relevant studies, one is what I call quasi-theoretical, as the individuals questioned were experts in the field of SL and likely had contributed to the very theoretical definitions they were questioned about. Yet this is an important contribution to the literature, to understand what components individuals may utilize in practice if they are aware of the entire landscape of possibilities. The current study focuses on individuals outside of the field of SL, graduate students in the sciences and science education. While the sample size is relatively small for this study, given the breadth of experience, range of disciplines, and equal gender distribution, this sample is fairly representative of the population of graduate students and therefore may be representative of the range of conceptions of graduate students in the sciences. The theoretical typology from Chapter 1 was used to compare the landscape of theoretical SL components with the practical definitions in the current study as well as the three complete, relevant studies. This top-down approach was complemented by a qualitative analysis of the natural intersections between science, literacy, and SL by plotting each unique idea (element) on a Venn Diagram to visualize points of natural overlap and deviation for the three domains. This was compared with the natural points of overlap between science and literacy in the literature for holistic differences between theoretical and practical definitions of SL. Finally, the number and type of components included in definitions of science, literacy, and SL were quantified and compared to demographic factors to determine if the amount of experience with science, graduate school, or outreach impacted the quality of response.

The first step to quantify the impact of demographic factors was to determine if the three chosen factors were correlated. While there was a moderate correlation between how long a participant had been in graduate school and how much experience they had with science, this was not significant. Further, there was no significant relationship between outreach experience and the amount of time a participant had been engaged in the scientific discipline, either as a graduate student or as they had perceived their involvement. This means that responses would have to be analyzed for each of these demographic factors separately, as engagement in outreach was dissociated from engagement in science, etc.

Each of the three demographic factors was therefore combined with each of the counts of the number of components included in definitions of science and SL. There was no significant impact of these demographic factors on quality of response, as measured by the number of components included in implicit and explicit definitions of science and SL, only a moderately negative correlation between outreach experience and the number of components included individuals' explicit definition of SL. This means that with more outreach experience individuals may be less explicit about what they include in their definitions of SL, but as this is not significant this trend may not hold with a different sample of the population. As there were no significant correlations between participant response and demographic factors, the remaining analyses were only separated by disciplinary focus, which played a large role in the theoretical analysis in Chapter 1.

The disciplinary trends found in the theoretical analysis of the natural intersection between science and literacy held for the current study as well. This demonstrates that even, or perhaps especially, in practice there is a much greater emphasis on the scientific discipline in SL than literacy or other related disciplines. In the theoretical distribution of plotted elements, there was a much greater emphasis on the scientific enterprise for science-focused researchers. This is found in the current study as well; the science-focused graduate students focused much more heavily on the influence of science on their definitions of SL than literacy or other intersecting domains. The disproportionate development of the science component of SL, as opposed to literacy or other domains, is unsurprising given the bulk of training for science graduate students is on the discipline of science itself. This emphasis on science is much greater than the theoretical literature, and leads to a typology that is much less balanced. However, the very small sample size of science education graduate students (n=1) may be the reason for the large, holistic differences between the theoretical and practical SL definitions. In the theoretical definitions the majority (if not all) of the intersections between literacy and SL stemmed from education-focused researchers. A larger sample size of science education graduate students may have contributed more elements to these intersections, mimicking the theoretical distribution of elements. Interestingly, the dissociation between literacy and science for science graduate students is reflected in the component analysis, with complete separation in the typology of science and literacy; science and literacy are completely complementary and mutually exclusive, and map directly onto the typology of their SL definitions. These together could reflect a role for literacy in definitions of SL for science graduate students, but rather than an integration of science and literacy to create a cohesive definition of SL, literacy and the scientific enterprise connect as distinct, interlocking pieces to form SL.

What pieces, exactly, are used to create this definition of SL? Rather than a conglomerate of all possible components, individuals focused on a subset of the theoretical typology. This is true for both the current study and previous studies, with even the experts only focusing on a subset of elements from one or two major components rather than providing a comprehensive theoretical definition (Kemp, 2002). In the other two prior studies, there were many theoretical components that were not present in practical responses (Brickhouse et al., 1989; Gabriel, 1976). Further, even among individuals with similar backgrounds, for example teachers, graduate students, science-focused, non-science focused individuals, there were intra-group differences in what was included in their practical definitions (see also Brickhouse et al., 1989; Gabel, 1976; Kemp, 2002). Individual differences in what aspects of science are presented to the public could have enormous implications for science education and outreach. A focus on the content of science would look very different dissociated from *how* science is done, and therefore how that content came to be and why it may change over time. A focus on the aesthetic qualities of science without a foundation of content would look very different from a focus on content without an appreciation for the beauty of nature. These sometimes-subtle differences in focus could lead to conflicting messages about what science *is* or what is important about science. However, there are some consistent trends across all studies, perhaps implying some consistency in the components that are most frequently cited as important. There is a focus on the content of science, but only as it can be applied. This practical focus is present in almost all relevant studies (perhaps only excluding Carlton, 1963), including the current study. This may run counter to the focus of many science educators, according to Gabel (1976):

> It would appear that many science educators have been operating from a perspective that is quite different from that of the 'layman's' perspective in terms of what is most important with regard to science for most high school graduates. The layman's perspective appears to be much more pragmatic than that of the science educator's. (pp. 254-255)

There are clear differences between the theoretical typology and practical definitions of

SL, but the question still remains as to the nature of practical definitions. Are practical definitions polysemic, complex, and multi-faceted like seen in the theoretical landscape? In short, yes. There is a mixture of goals, aims and objectives that define SL, for example in Kemp (2002) the three main emphases are what people should know, what they should be able to do, and how they should feel (Figure 5). Even within a somewhat homogenous group of individuals, there is no consensus as to what the main focus of SL should be in this study or prior, relevant literature (Brickhouse et al., 1989; Gabel, 1976; Kemp, 2002). This is perhaps due to its multi-faceted nature; SL is more than just the combination of science and literacy, including several other domains it its definition, and one can be scientifically literate in many different ways. In the current study, there were two participants that explicitly talked about SL being a gradient. For example, from P5: “[Science] literacy is not black-and-white; in other words, it's not "you either have it or you don't". There are gradations. As a (scientific) example, one might understand a physics piece tackling F = m*a, but fall vastly short of understanding quantum mechanics”. All participants in Kemp’s study (2002) agreed that SL is a continuum, meaning “everyone who has a ‘normally’ functioning brain is scientifically literate at some level; and different individuals are scientifically literate to different degrees” (p. 257). Finally, practical definitions of SL may evolve over time, reflecting the snowball effect in the theoretical landscape in which components from each successive educational paradigm are included in the definition of SL. Further work will need to be done to elucidate if this is a simple accumulation of conceptions over time, a reflection of the various educational paradigms, or a trend towards greater visibility of SL as a discipline. It seems that the practical definitions of SL are just as complex, multi-faceted, and polysemic as the theoretical definitions. However, there still may be more of an emphasis on the practical application of this dynamic knowledge, making these definitions more cohesive and focused than the entire landscape of theoretical components. This means that the amorphous theoretical landscape of SL cannot be used to predict practical conceptions of SL, though this is a good starting place to understand the diversity of practical definitions of SL. If there are conflicting messages about what science *is,* or its goals, between students and teachers this can impact what the public

Limitations and Future Work

While the sample size is small, and there is only one individual from science education, given the breadth of departments and range of experience of the participants the study is fairly representative of the diversity within science graduate students, ranging from first to fifth year students, from 5-15 years of experience with science, and from expert-level to some outreach experience. Further, there is a balance of both males and females in this study. What this study is sorely lacking is any deviation from Non-Hispanic White participants. Further, there is very little diversity in institution, with only one participant outside of the single large R1 institution, and all institutions focused on research over teaching and outreach (Research 1 institutions). Future work would benefit from including many institution types, especially comparing the differences between graduate students in research focused versus teaching focused universities. While their impact is large, graduate students are only one population of professionals that engage with the public about science. It will be imperative to understand how other professional scientists, as well as other professionals that deal with science education, outreach, communication, and journalism conceptualize scientific literacy to fully understand our impact on public perception of science. Finally, there were several concepts that didn't readily align with the components in the theoretical scheme in both the current study and in previous literature. While none of these were ubiquitous among participant responses, these could still be used to expand or revise the current theoretical typology. This typology was meant to be dynamic, modified with new empirical data and shifts in conceptions of SL over time. Future empirical studies can redirect and shape this theoretical typology to capture the landscape of conceptions of SL.

Conclusions

Graduate students are poised to have a large impact on their communities' understanding of science, through formal and informal teaching, public outreach, and dissemination of scientific information within and beyond the academic community. Therefore it is imperative that we understand not only the landscape of theoretical notions of SL, but the conceptions that individuals utilize in practical settings. This study focuses on the former in Chapter 1, building a typology of theoretical SL components, and the latter in Chapter 2, applying this typology to both the implicit and explicit conceptions of SL, science, and literacy for graduate students in the sciences and science education to know which of these theoretical components are utilized in practice and what these individuals may pull on beyond these theoretical components. There have been very few studies on practical conceptions of SL, and even fewer that have enough information to compare to or replicate in future studies, despite its importance for the public understanding of science. This serves as a bridge between theoretical definitions of SL and the body of literature measuring SL in the public, to understand the messages the public is receiving about science in *practice* and not just what the public should know in *theory.* I find that while there are many points of overlap between the theoretical and practical components of SL, there are many more differences. There is a much greater emphasis on the science component of SL in practice, and this is coupled with a focus on the application of the scientific enterprise in one's everyday life. This is true both for the current study and the handful of relevant studies in this area. Further, the practical conception of SL is much less coordinated and cohesive, with only a small intersection between science, literacy, and SL. This heavy focus on science, and especially science content, as well as application must be understood in relation to the theoretical literature base, but must go beyond this to understand how these conceptualizations of SL can impact the realization of SL in the public. It is only once we understand how SL is defined in its everyday application that we can begin to understand what this means for public understanding of science.

Figures

Figure 4 – Kemp (2002) Table 4.1, Elements of SL in Each Dimension, by Individual

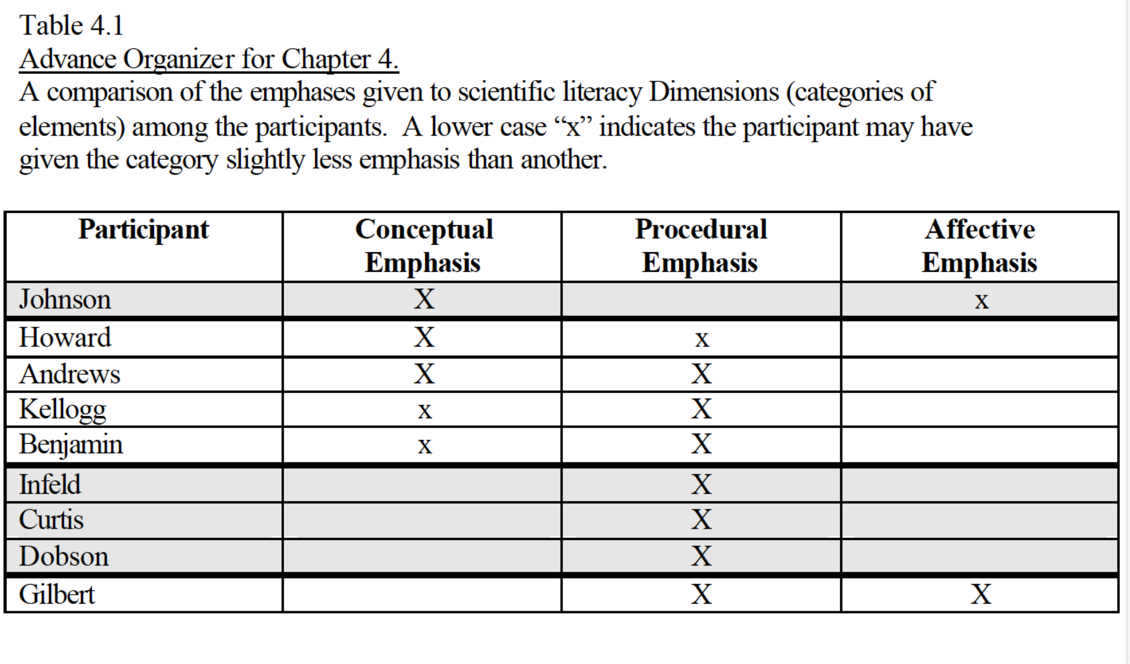


Table 4.1

Advance Organizer for Chapter 4.

A comparison of the emphases given to scientific literacy Dimensions (categories of elements) among the participants. A lower case “x” indicates the participant may have given the category slightly less emphasis than another.

Participant	Conceptual Emphasis	Procedural Emphasis	Affective Emphasis
Johnson	X		x
Howard	X	x	
Andrews	X	X	
Kellogg	x	X	
Benjamin	x	X	
Infeld		X	
Curtis		X	
Dobson		X	
Gilbert		X	X

Figure 5 – Kemp (2002) Table 4.2, Elements of SL in Each Dimension, Composite

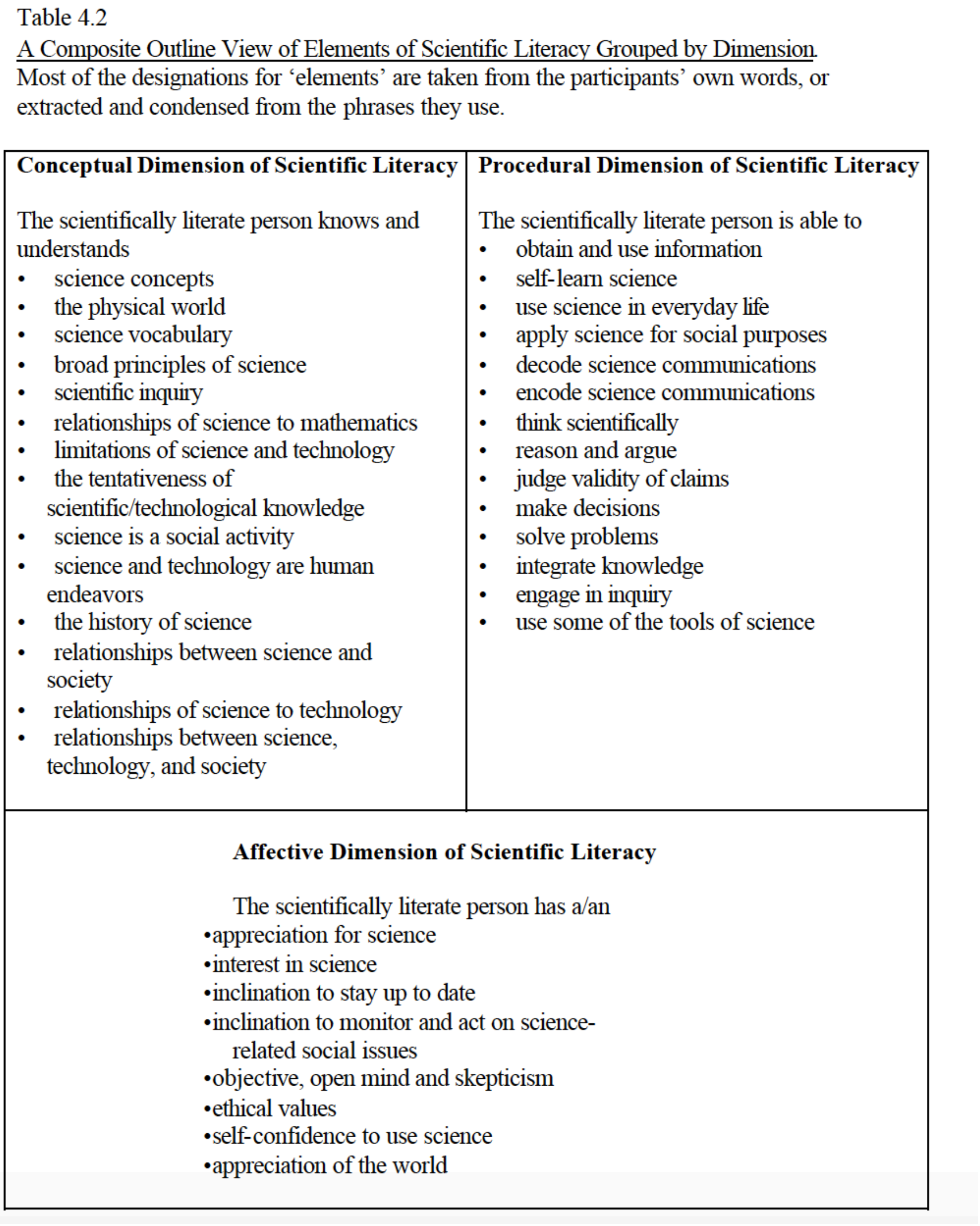


Table 4.2

A Composite Outline View of Elements of Scientific Literacy Grouped by Dimension. Most of the designations for 'elements' are taken from the participants' own words, or extracted and condensed from the phrases they use.

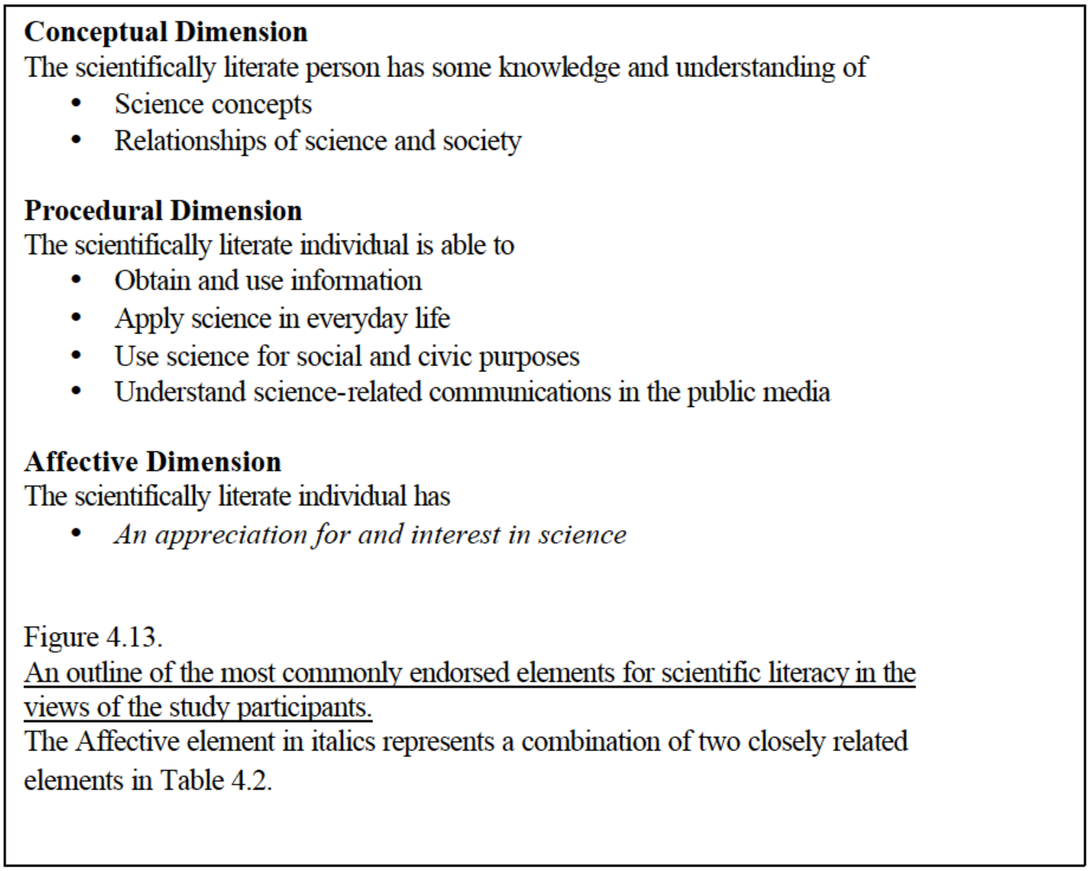
Conceptual Dimension of Scientific Literacy	**Procedural Dimension of Scientific Literacy**
The scientifically literate person knows and understands • science concepts • the physical world • science vocabulary • broad principles of science • scientific inquiry • relationships of science to mathematics • limitations of science and technology • the tentativeness of scientific/technological knowledge • science is a social activity • science and technology are human endeavors • the history of science • relationships between science and society • relationships of science to technology • relationships between science, technology, and society	The scientifically literate person is able to • obtain and use information • self-learn science • use science in everyday life • apply science for social purposes • decode science communications • encode science communications • think scientifically • reason and argue • judge validity of claims • make decisions • solve problems • integrate knowledge • engage in inquiry • use some of the tools of science

Affective Dimension of Scientific Literacy

The scientifically literate person has a/an

- appreciation for science
- interest in science
- inclination to stay up to date
- inclination to monitor and act on science-related social issues
- objective, open mind and skepticism
- ethical values
- self-confidence to use science
- appreciation of the world

Figure 6 – Kemp (2002) Figure 4.13, Commonly Endorsed Elements of SL



Conceptual Dimension
The scientifically literate person has some knowledge and understanding of

- Science concepts
- Relationships of science and society

Procedural Dimension
The scientifically literate individual is able to

- Obtain and use information
- Apply science in everyday life
- Use science for social and civic purposes
- Understand science-related communications in the public media

Affective Dimension
The scientifically literate individual has

- *An appreciation for and interest in science*

Figure 4.13.
An outline of the most commonly endorsed elements for scientific literacy in the views of the study participants.
The Affective element in italics represents a combination of two closely related elements in Table 4.2.

Figure 7 – Correlation between demographics and SL components, analysis scheme

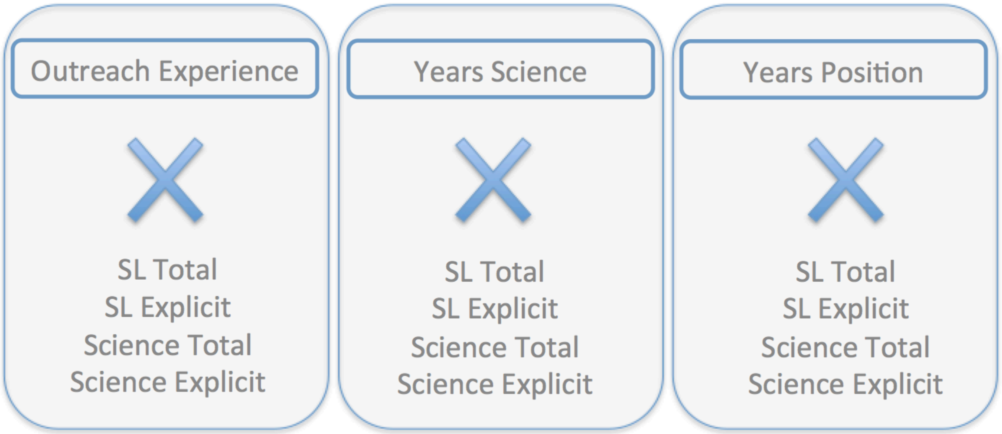


Figure 8 - Participant Demographics, Years Experience with Science

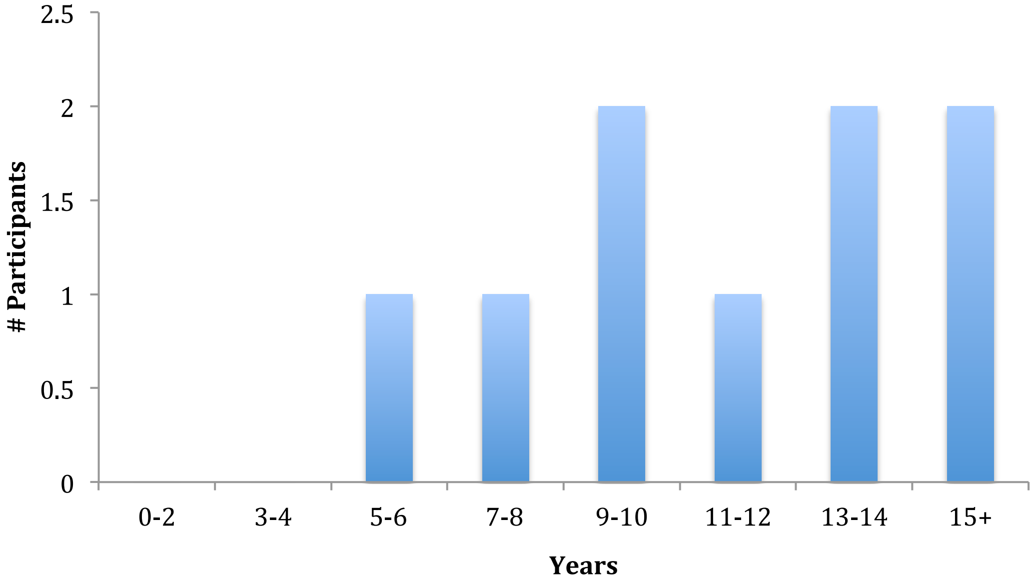


Figure 9 - Participant Demographics, Years in Current Position

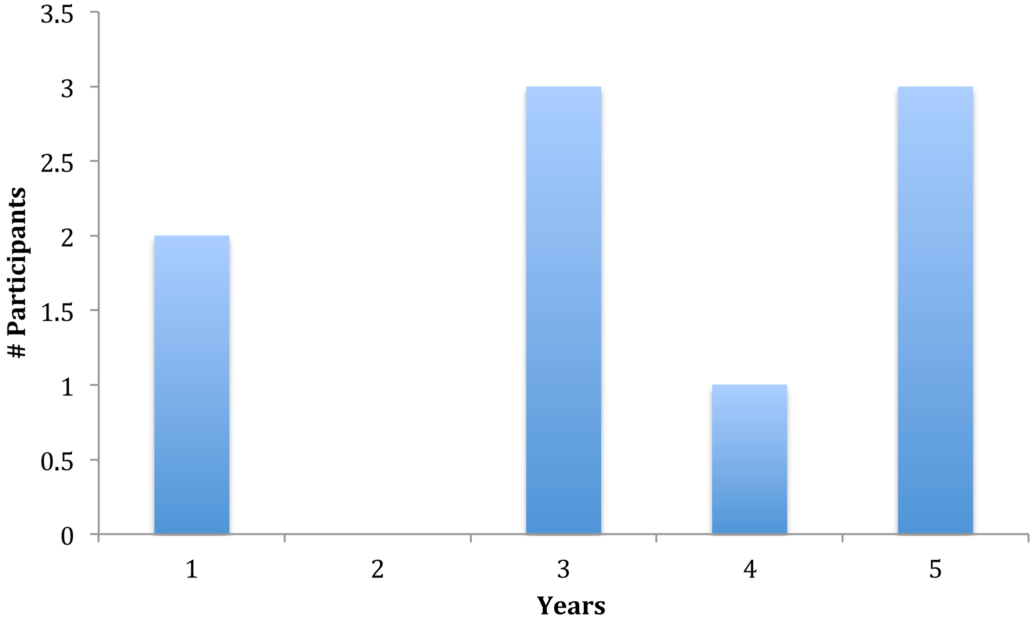


Figure 10 - Participant Demographics, Outreach Experience

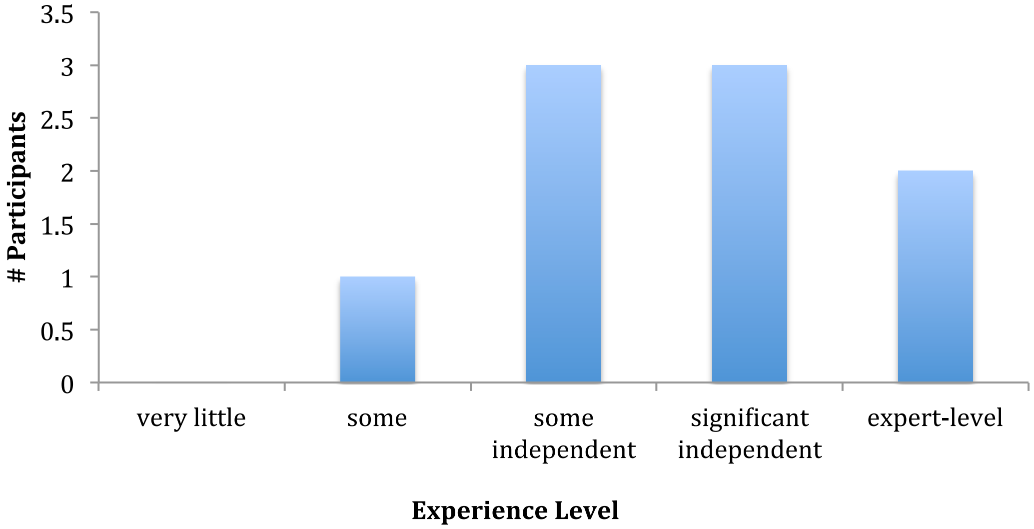


Figure 11 - Quantitative Analysis, Years Science x Years Position

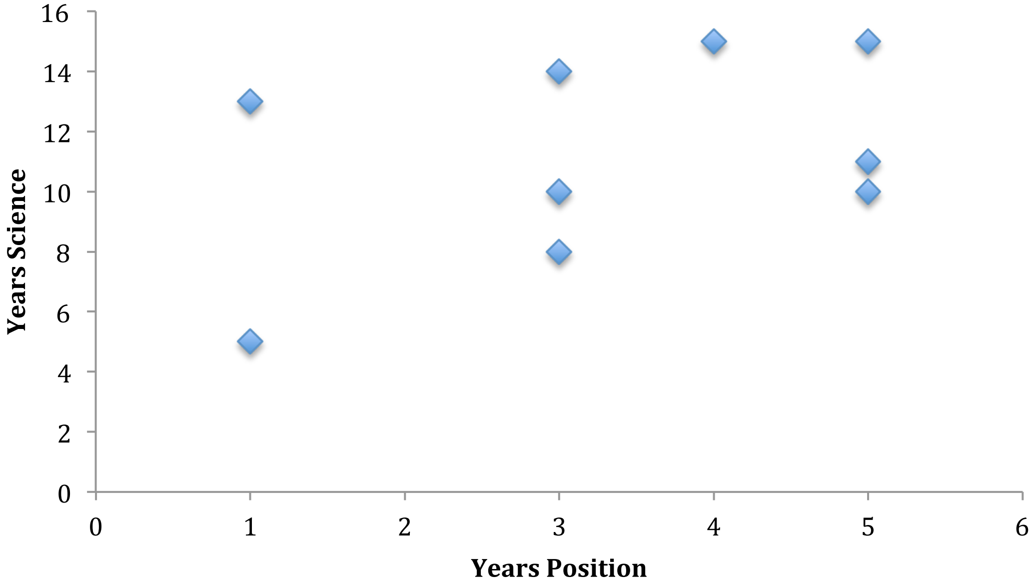


Figure 12 - Quantitative Analysis, Outreach Experience x Total Number of SL Explicit Components Included

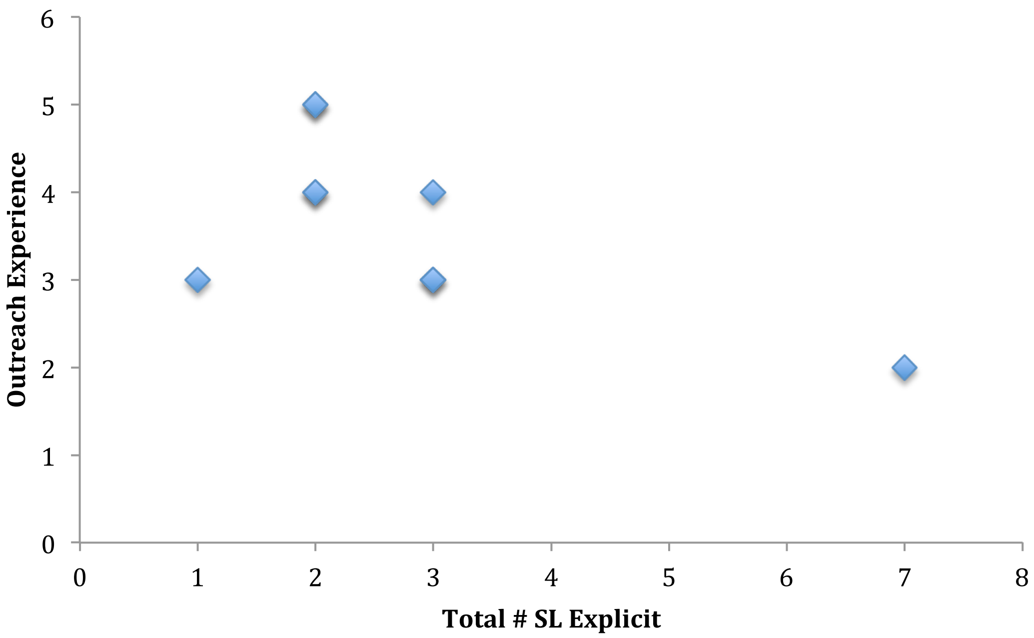
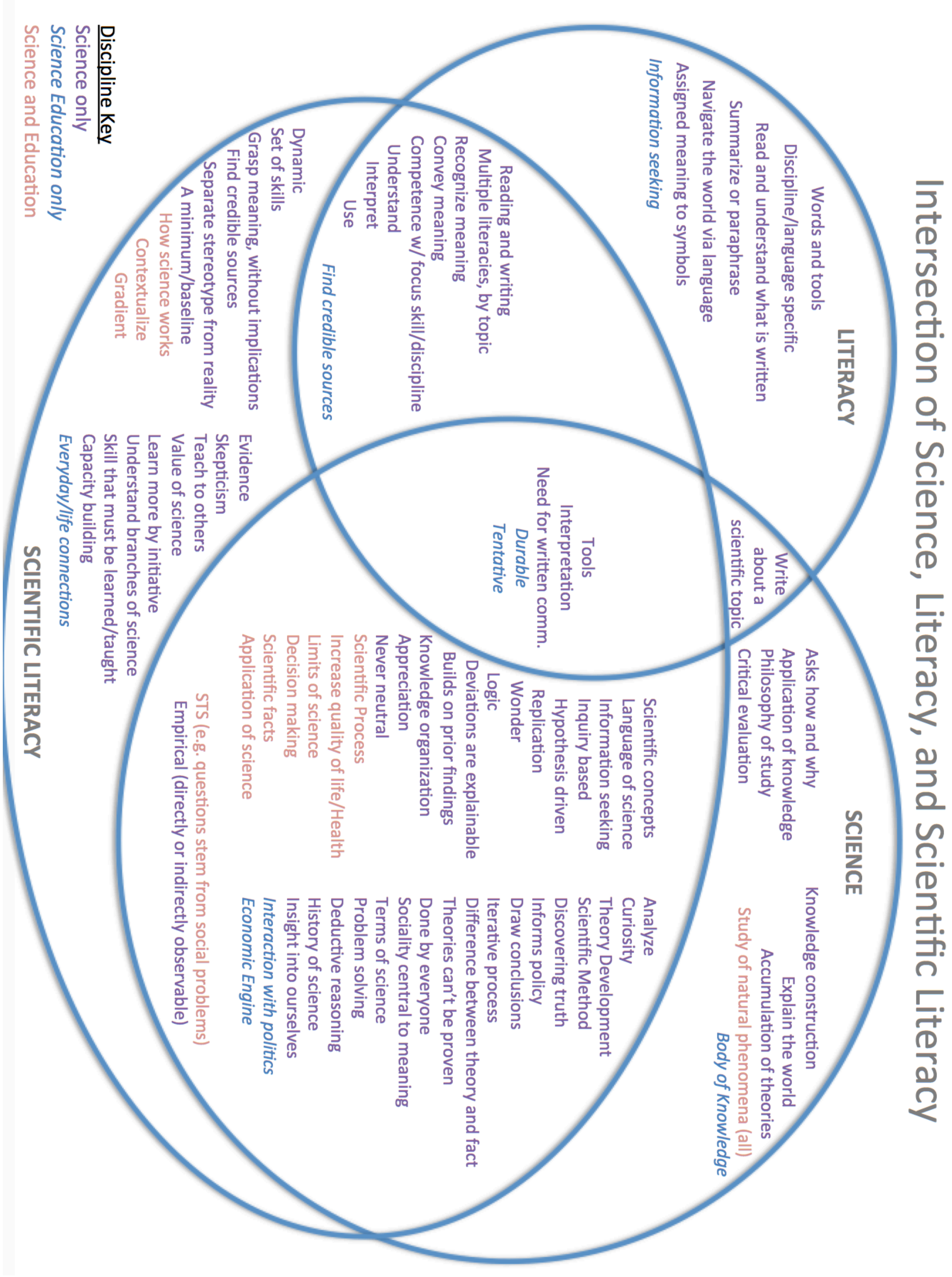


Figure 13 – Practical intersection of science, literacy, and scientific literacy, by discipline



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APPENDIX A: SL DEFINITIONS BY DISCIPLINE

Table 13 – Definitions and supporting quotes for scientific literacy in the fields of science (science researchers)

Author, Year	Content type	What is SL
AAAS, 1989	Definition	"The scientifically literate person is one who: is aware that science, mathematics, and technology are interdependent enterprises with strengths and limitations, understands key concepts and principles of science; is familiar with the natural world and recognizes both its diversity and unity; uses scientific knowledge and scientific ways of thinking for individual and social purposes" (p. 12)
AAAS, 1990	Definition	"Scientific literacy – which encompasses mathematics and technology as well as the natural and social sciences – has many facets. These include being familiar with the natural world and respecting its unity; being aware of some of the important ways in which mathematics, technology, and the sciences depend upon one another; understanding some of the key concepts and principles of science; having a capacity for scientific ways of thinking; knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths and limitations; and being able to use scientific knowledge and ways of thinking for personal and social purposes" (pp. *xvii-xviii)*
Shen, 1975	Definition	"We may define scientific literacy as an acquaintance with science, technology, and medicine, popularized to various degrees, on the part of the general public and special sectors of the public through information in the mass media and education in and out of schools." (p. 45-46) "We may divide the myriad activities that fit the definition of scientific literacy into three categories: practical, civic, and cultural. To be sure, these categories are not mutually exclusive; science teaching in the schools, for instance, can fall under all three" (p. 46) "By practical scientific literacy, I mean the possession of the kind of scientific knowledge that can be used to help solve practical problems. Since the most basic human needs are health and survival, it is not surprising that much of practical scientific literacy has to do with just those needs" (p. 46) "The aim of civic scientific literacy is precisely to enable the citizen to become more aware of science and science-related issues so that he and his representatives would not shy away from bringing their common sense to bear upon such issues and thus participate more fully in the democratic processes of an increasingly technological society." (p. 48) "Cultural scientific literacy is motivated by a desire to know something about science as a major human achievement. It is a cultural adventure. It is to science what art appreciation is to art. It solves no practical problems, but it does help bridge the widening gulf between the 'two cultures'" (p. 49)

Table 13 (cont.)

	Support	"Practical scientific literacy [is] the most urgently needed but often the most neglected of the three...the availability of a few pieces of essential scientific information can mean the difference between health and disease, life and death." (pp. 46-47) "To achieve a functional level of civic scientific literacy, at least two things need to be done. First, the public over the long term must be far more exposed to science than they are today...Second, the science behind specific science-related public issues of current interest must be analyzed in plain English for the average citizen on a continuing basis by specialists in explicating science." (p, 48) "Familiarity with science and awareness of its implications are not the same as the acquisition of scientific information for the solution of practical problems. In this respect civic scientific literacy differs fundamentally from practical scientific literacy. We should accept the fact that it is not the purpose of cultural scientific literacy, or of any kind of scientific literacy, to train science hobbyists or future scientists." (p. 49)
Raymo, 1998	Objective	"Here are six bits of knowledge that should constitute minimum scientific literacy for every grade-school graduate. They should not be hard to teach, if one year of the curriculum were devoted to each: 1. The world is big. With our best telescopes we observe a universe of tens of billions of galaxies. Each galaxy consists of hundreds of billions of stars. Most of those stars probably have planet systems. Our Earth is a typical planet of a typical star in a typical corner of a typical galaxy. 2. The world is old. Human time is not cosmic time. If a year is represented by the thickness of a playing card, all of recorded human history would be a pile of cards about 10 feet high. The age of the universe is about 15 billion years; lay this pile of cards on its side and it would reach from New York to San Francisco. 3. The world is made of atoms. Nature's construction set is astonishingly simple—protons, neutrons, electrons. Of these, nature makes 92 kinds of atoms, and these combine into molecules. Out of simplicity comes complexity—the clear liquidity of water, the smell of bananas, the blue of the sky. A molecule called DNA determines your species, your gender, the color of your eyes. 4. The world evolves. The history of the universe is a grand unfolding of matter and form from a seed of pure energy. Stars, planets, and life have histories, determined by law and contingency—life and death, building up and tearing down, beauty and terror. Everything alive on the planet Earth today is related by common descent from primordial ancestors. 5. Everything is connected. Our bodies are made of stardust—atoms forged in earlier generations of stars as they lived and died. Stars, planets, plants, animals, rocks, soil, sea, and atmosphere are interrelated in a fabric of wondrous refinement and resilience. We disrupt the fabric at our peril. 6. The world is wonderful. The more we learn about the form and function of the world, the more we realize the depth of our ignorance, and the more we appreciate the creation as a source of wonder, awe, reverence, praise—or as revelation of a power worthy of

		our wonder, awe, reverence, praise. These six ‘‘facts’’ are the product of thousands of years of human curiosity, creativity, and discovery. They should be the proud inheritance of every human child. They are the bedrock of scientific literacy". (p. 752)
Devlin, 1998	Objective	"It is neither possible nor necessary for the general population to have detailed scientific knowledge across a range of disciplines. Instead, what is important is scientific awareness—an understanding of what the scientific enterprise is about, what a scientist means by the word ‘‘theory,’’ and what it means to establish a 'scientific fact'" (p. 559) "When I say that all adults should be scientifically aware, I mean that they should base their opinion on fact and observable evidence rather than on prejudice or assumptions; they should be willing to change their opinions based on new evidence, understand cause and effect relationships, and appreciate how science is done—in particular understand the role played by observation and experiment in establishing a scientific conclusion; and they should know what the terms ‘scientific theory’ and ‘scientific fact’ mean" (p. 559)
	Support	“I think it is pointless to define scientific literacy in terms of any particular body of scientific knowledge. I neither know nor understand most of present-day science. And yet I am a dean of science at a private four-year college, an active researcher, and the author of several mathematics textbooks and science books for the general reader.” (p. 559)
Miller, 2004	Definition	"Miller (1983a, 1986, 1987a, 1995, 1998a, 2000) has defined the level of understanding needed for scientific literacy to be sufficient to read and comprehend the Tuesday science section of The New York Times." (p. 274)

Table 14 – Definitions and supporting quotes for scientific literacy in the field of education (education researchers)

Author, Year	**Content type**	**What is SL**
21stCentury Science.org	Objective	"We would expect a scientifically literate person to be able to: appreciate and understand the impact of science and technology on everyday life, take informed personal decisions about things that involve science, such as health, diet, use of energy resources, read and understand the essential points of media reports about matters that involve science, reflect critically on the information included in, and (often more important) omitted from, such reports, and take part confidently in discussions with others about issues involving science"
Aikenhead, Orpwood, & Fensham, 2011	Objective	"SL in a Knowledge Society is necessarily literacy-in-action - oral, written, and digital literacy-in-action. Consequently SL as an educational outcome takes on an active, rather than a passive connotation. SL is not about 'How much do you know?' but instead 'What can you learn when the need arises?' *and* 'How effectively can you use your learning to deal with ST-related events in the work world or the everyday world of citizens?'" (p. 31) "In short, acquiring knowledge ("knowing that") would be replaced by *capacity building* ("knowing how to learn and knowing-in-action") as the primary mission for school science. For a Knowledge Society, the primary meaning for SL becomes SL-in-action" (p. 32) "A Knowledge Society requires employers, employees, and citizens to develop the capacity to treat knowledge in terms of action - knowing-in-action. In science education this becomes SL-in-action" (p. 41)
Deng, 2011	Other	"Economic discourse underlines the need for a scientifically literate workforce for economic growth...it advocates...the development of technical skills and 'know how'" "Political discourse stresses the need for a scientifically literate public for political/social development, calling for the cultivation of informed decision-making capacities" "(World) cultural discourse...calls attention to the importance of developing personal relevance and individual agency, of encouraging the participation of students of diverse background and ethnicities, and of strengthening science, technology, and mathematics for all students in the school curriculum" (p. 47)
Kelly, 2011	Definition	"I have argued for a view of scientific literacy that considers the ways that language use is central to the development of community knowledge and practices" (pp. 69-70)

Table 14 (cont.)

Liberg et al., 2011	Definition	"Becoming scientifically literate can be seen as a broadening of ways of formulating subject matter that ranges from more concrete to more specified and specific activities. This is a development of an increasing repertoire of ways of expressing yourself. Scientific literacy, as well as learning in general, can thus be considered to be the cumulative development of evermore active participation in social practices, where different ways of expressing oneself and talking about the world are used. Being an active participant also includes becoming a co-creator of the social practices one is involved in [and this will result from] an extensive repertoire of text movability, [the ability to talk about the texts you have read or have written yourself]" (p. 74)
	Support	"[there are several] language dimensions considered central to scientific literacy. The dimensions discussed here are genre, abstraction, lexical density, logical relations, objectivity, and multimodality" (p. 75) "A dimension of becoming scientifically literate is thus the development of being able to participate in these different types of genres [doing science, explaining events scientifically, organizing scientific information, and challenging science]" (p. 77) "A dimension of being scientifically literate is thus being able to move back and forth between more congruent and everyday language to a more incongruent, technical and packed language" (p. 77) "Becoming scientifically literate involves being able to use this kind of objective and authoritative language" (p. 78) "Scientific literacy includes among other things a repertoire of languageing in reading, writing, and talking science that embraces both more restricted and more developed ways of languageing. It also includes an ability to easily move between a more restricted and a more developed languageing. By this means it becomes possible to both adapt to a context and at the same time be able to be a co-creator of a new one" (p. 87) "The language of science differs from the language in other subjects in several ways" (p. 75) Note: all language dimensions they mention are central to scientific literacy, but only a few are explicitly connected back to literacy in their descriptions

Table 14 (cont.)

Martins, 2011	Definition	“The ideas expressed so far can be potentially useful for a revision and expansion of the concept of SL. The first aspect to be emphasized is the diversity of perspectives through which the concept can be approached...a second aspect concerns acceptance that scientific knowledge is a necessary, though not sufficient, element in the fostering of responsible citizenship...a third aspect recognizes that rational conviction alone may not lead directly to the adoption of responsible behavior [and this may be explained by cultural perspectives or affective and emotional bases of the relationship between individuals and knowledge]” (p. 100) "In accordance with Roberts (2007), one part of the definitions found in the literature is based on science's own internal agenda, identified by its products, processes, and agents. Only a fraction of the studies Roberts reviewed including understanding the nature of science and scientific activity, together with the process of production of the scientific knowledge, amongst the contents to be mastered by the scientifically literate person. A step further would be the adoption of a critical perspective, which would lead individuals to question the objectives of science and to propose alternatives based upon these reflections. In fact, the adoption of critical perspectives for education distinguishes functional SL (where citizens adjust to the society and contribute to its progress, strengthening and consolidating already established relations) from emancipatory SL (in which people engage not only in practices that transform their conditions in society but also in practices that change society itself)" (p. 101)
	Support	"Critical approaches to language and discourse can help us question the overrated importance given to discussions about which specific bits of knowledge, technical terms, or vocabulary scientifically literate people should possess-which are quite common in the agenda of the SL projects identified with what Roberts (2007) identifies as Vision I" (p. 92) "According to [the views of language as a code system], which have been quite influential in the structuring of traditional science curricula, SL is achieved by learning the building blocks of knowledge in order to be able to reach more complex levels of representation. Likewise, they inspired many large-scale surveys of public understanding of science conducted in the 1980s, which actually measured the ability to recall factual information" (p. 98) "from emancipatory perspectives, the answer to the question of why we should promote SL is not defined solely by the nature of science or scientific activity but by the need to transform men and women into citizens. In this way, they reinforce views that school science is not just a didactically authorized version of scientific knowledge, but new knowledge that arises from an amalgamation of scientific, ethical, moral, cultural, pedagogical, and commonsense knowledge" (pp. 98-99) "The necessity of becoming proficient in different modalities, namely verbal, visual, computation, and so forth, is already recognized as part of

the demands for multimedia literacy in science curricula and in communication in general...efforts to achieve SL involve the consideration of the multimodal nature of [scientific texts and their authorized versions]." (p. 99)

"[I analyze and extend the concept of literacy from Soares (2003)] so as to elaborate a view in which SL is seen not just as a pedagogical issue but also as a political issue, that is, an investment in humanist and liberating praxis" (p. 91)

"anthropological perspectives [of literacy, or practices aimed at introducing students to scientific culture] highlight the potential of SL for enabling significant changes in how one perceives and signifies reality. This is usually expressed by changes from phenomenological to theorized language"

"[The linguistic dimension] highlights the importance of acquiring scientific vocabulary and of becoming familiar with technical terminology" (p. 96)

"In order to accomplish this goal [of promoting SL through the instrumentalization of individuals for responsible decision making in society] literacy cannot be seen just as a pedagogical issue. It has to be conceptualized as a political issue, that is, as an investment in humanist and liberating praxis" (p. 97)

Table 15 – Definitions and supporting quotes for scientific literacy in fields other than science or education

Author, Year	**Discipline**	**Content type**	**What is SL**
Burbules & Linn, 1991 *Note: Researchers are split between Education and Philosophy, so not shown in Table 3*	Education, Philosophy	Objective	"Science education should help students (a) acquire a basic knowledge and understanding of ordinary scientific phenomena; (b) develop the ability to generate fruitful and relevant questions and frame them in an effective way for investigation; (c) learn to select and apply appropriate methods from a range of options in answering those questions; and (d) evaluate and synthesize the scientific information gained as a result" (pp. 228-229) "Like many others, we advocate a move away from science education based on learning 'facts' and technical vocabulary. We want to encourage approaches that help students learn to formulate and test hypotheses as a means of constructing new understandings. But students also need to have a sound and realistic view of the nature of the scientific enterprise itself. Traditional approaches to science education frequently assume a static view of scientific knowledge and present a single 'method' that purportedly characterizes all scientific investigation. Instead, students should learn to find and integrate multiple converging sources of information. They should gain an appreciation of how achievements in science actually come about - including the recognition that the processes of scientific investigation are imperfect. Scientific literacy in the fullest sense should include both a healthy respect for the achievements and methods of science and a healthy skepticism concerning the finality of scientific truth. Such an attitude underlies both a more realistic assessment of how science happens, and a more democratic accessibility to science as a tool of human inquiry rather than as an impersonal 'black box' of authoritative 'facts' " (p. 229)

Table 15 (cont.)

Maienschein & students, 1998	History and Philosophy of Science	Definition	"…two different definitions of scientific literacy. The first emphasizes practical results and stresses short-term instrumental good, notably training immediately productive members of society with specific facts and skills. We call this scientific literacy, with its focus on gaining units of scientific or technical knowledge. Second is scientific literacy, which emphasizes scientific ways of knowing and the process of thinking critically and creatively about the natural world. Advocates of the second assume that it is good to have critical thinkers, that scientific literacy is an intrinsic good—on moral and other principled grounds. Being scientifically literate helps people to live “good” lives (in the philosophers' sense of reflective and fulfilling, and not in the distasteful sense of eating good-for-you bran flakes). According to this view, science is beautiful, exciting, and fun. Becoming scientifically literate produces skeptical, creative habits of mind that are valuable for everyone." (p. 917)
	History and Philosophy of Science	Support	"The two approaches are often in tension and have different implications for education, testing, and public funding of science. Promoting scientific literacy requires a new way of teaching for which few teachers are prepared. It stresses long-term process over short-term product and questions over answers. The student may possess less knowledge, but has skills for adapting to the challenges of a rapidly changing world." (p. 917) "we advocate integrating the short-term goals of knowing science (facts and skills) and the long-term goals of scientific literacy. We must have a society rich in both critical, creative scientific thinkers and enough knowledgeable experts to do today's work. We need both scientific literacy and scientific literacy for effective participation in the real world." (p. 917)

APPENDIX B: SL CONTENT CODES

Table 16 – Content codes for scientific literacy definitions, from the field of education (researchers in education)

Author, Year	Content type	Codes			
		Science	Literacy	Both	Other
21stCentury Science.org	Objective		- Discussions about science - Alphabetic literacy	- Critical thinking	- Impact of science and technology on everyday life - Make informed personal decisions
Aikenhead, Orpwood, & Fensham, 2011	Objective		- "literacy-in-action" - oral vs. written	- shaped by technology - "capacity building" (knowing-in-action)	- digital literacy
Deng, 2011	Other		- discourse type		- technical skills, "know how" - economic growth - political/social development - decision making capacity - agency - diverse representation
Kelly, 2011	Definition		- language central to knowledge - context dependent (inferred)		- community of practice
Liberg et al., 2011	Definition		- identity formation - participation as a member (inferred) - co-creation of meaning	- acculturation - deep connection, understanding	

Table 16 (cont.)

	Support		- co-creation of meaning - oral vs. written - lexical density - logical relations	- multiple distinct genres - move between technical and everyday language - use/apply the language of science - multimodal	
Martins, 2011	Support	-technical terms	phenomenological to theorized language	- vocabulary - multimodal	- liberating praxis - change in perception - culture of science
	Definitions	- challenging science - content	- metacognition (inferred)	- evaluation (inferred) - critical thinking - ability to transform social conditions	- citizenship - affect/emotion - change society
Burbules & Linn, 1991 *Note: Researchers are split between Education and Philosophy, so shown in Table 7 as well*	Objective	- understand the "scientific enterprise" - tentative nature - no single method - achievements of science - strengths and limitations - one of many ways of knowing (inferred) - Content - Experimental design - Production of knowledge (inferred)		- hypothesizing - Evaluation - Synthesis (esp. from multiple sources) - language of science	- skepticism

Table 17 – Content codes for scientific literacy definitions, from the fields of science (researchers in science fields)

Author, Year	**Content type**	**Codes**			
		Science	**Literacy**	**Both**	**Other**
AAAS, 1989	Definition	- Strengths and limitations - Content (familiar with natural world)	- Developing ways of thinking		- Science, math, and technology are interdependent - Application for individual and social purposes
AAAS, 1990	Definition	- Strengths and limitations - Content (familiar with natural world) - human enterprise	- Developing ways of thinking		- Science, math, and technology are interdependent - Application for individual and social purposes - includes natural and social sciences
Shen, 1975	Definition	- culture of science			- acquaintence with science, technology, and medicine - solve practical problems (health, survival) - awareness of science-related issues - common sense - participate in democratic process - Art-like appreciation for science
Raymo, 1998	Objective	- content - creative		- human endeavor	- Art-like appreciation for science
Devlin, 1998	Objective	- understand the "scientific enterprise" - theory and law distinct			- awareness of science-related issues
	Objective	- evidence-based reasoning - explaining scientifically (cause and effect relationships) - empirical (observation and experimentation produces knowledge) - Doing science			
Miller, 2004	Definition	- content		- concept formation	

Table 18 – Content codes for scientific literacy definitions, from fields other than education or science

Author, Year	**Content type**	**Codes**			
		Science	**Literacy**	**Both**	**Other**
Maienschein & students, 1998	Definition	- Creative - One of many ways of knowing (implied) - way of knowing - content - technical terms	- Developing ways of thinking	- Critical thinking	- an intrinsic "good" - morality - science is beautiful, exciting, and fun - skepticism - productive members of society
	Support			- "capacity building" (knowing-in-action)	
Burbules & Linn, 1991 *Note: Researchers are split between Education and Philosophy, so shown in Table 5 as well*	Objective	- understand the "scientific enterprise" - tentative nature - no single method - achievements of science - strengths and limitations - one of many ways of knowing (inferred) - Content - Experimental design - Production of knowledge (inferred)		- hypothesizing - Evaluation - Synthesis (esp. from multiple sources) - language of science	- skepticism

APPENDIX C: INFORMED CONSENT STATEMENT AND ONLINE SURVEY

Science Communication Consent Form

Who: Researchers at the University of Illinois at Urbana-Champaign (UIUC), College of Education
Research Interests: As science researchers we spend a lot of time and money on public outreach, and it is essential to understand the impact of these efforts. An aim of my research is to understand the connection between the ways we talk about science and public science literacy. Your responses will help immensely in understanding the impact of science communication on how the public understands science.
What: You will be responding to an open-ended survey with prompts about science and science communication. You may complete the survey at any time and place of your choosing, using an internet-enabled device. Taking part in this research study may not benefit you personally, but we [researchers] may learn new things that will help others. There are no costs to you for participating in this research
Risks: This research does not involve risks beyond those normally encountered online or in everyday life.
Duration: The time required to answer the survey questions would be approximately one hour. The survey will close after four weeks, after which you will not be able to complete the survey.
Participation: Participation is completely voluntary. You are not required to participate in the study if you do not wish to do so and you may decline to continue at any time. Further, you are free to withdraw your permission to participate at any time and for any reason. If you do participate, your responses will help broaden our understanding of how researchers engage with the public about science.
Survey Questions: You will be asked to respond to six questions about science and science communication. They are open-ended and responses should be based on your own opinions and experience.
Confidentiality: Any sharing or publication of the research results would occur only during educational presentations and with your specific consent. Your data will be coded with a participant number and not your name. No internal or published material will identify any of the participants by name, nor will it be made publically available online. If you prefer to take a physical copy of the survey, linking yourself with the research, you may request one by contacting the primary investigator. In general, we will not release any information about you, only the anonymized survey results. However, laws and university rules might require us to disclose information about you. For example, if required by laws or University Policy, study information may be seen or copied by the following people or groups: a) The university committee and office that reviews and approves research studies, the Institutional Review Board (IRB) and Office for Protection of Research Subjects, or b) University and state auditors, and Departments of the university responsible for oversight of research.
Contact Info: Please feel free to ask us any questions you may have. We will be happy to answer your questions.
Barbara Hug (Primary Investigator):

bhug@illinois.edu
Office Phone: 217-244-9090
Department of Curriculum & Instruction,
Room 302, 1310 South Sixth Street,
University of Illinois, Urbana-Champaign
If you have any questions about your rights as a participant in this study or any concerns or complaints, please contact the University of Illinois Institutional Review Board at 217-333-2670 or via email at irb@illinois.edu

Remember, your participation in this research is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University. If you decide to participate, you are free to withdraw at any time without affecting that relationship. Please print a copy of this consent form for your records, if you so desire.

*1. I have read and understand the above consent form, I certify that I am 18 years old or older and, by checking the box below and clicking the next button to enter the survey, I indicate my willingness voluntarily take part in the study.

☐ I have read (or someone has read to me) the above information and I agree voluntarily to participate in this research.

Science Communication Demographics Form

Gender [optional]:
- ☐ Male
- ☐ Female
- ☐ Transgendered
- ☐ Other
- ☐ I prefer not to respond

Ethnicity [optional]:
- ☐ Hispanic
- ☐ Non Hispanic
- ☐ I prefer not to respond

Race [optional]:
- ☐ American Indian (AI) / Alaskan Native (AN)
- ☐ Native Hawaiian (NH) / Pacific Islander (PI)
- ☐ Black (B) / African-American (AA)
- ☐ White (W)
- ☐ Asian (A)
- ☐ More than one race reported (AI/AN, NH/PI, B/AA)
- ☐ More than one race reported (W, A)
- ☐ I prefer not to answer.
- ☐ Other __________________

*Current University: ______________________________________

Current Department: ______________________________________

*Graduate Degree Focus
- ☐ Science
- ☐ Science Education
- ☐ Philosophy of Science
- ☐ Other________________________

*Years in current position: __________________________

*Years experience with Science: __________________________

*Describe your experience with science in a sentence or two:

*Experience with outreach

☐ Very little experience

☐ Some experience (e.g. helping at booths)

☐ Some independent experience (e.g. developing activities, writing blog posts)

☐ Significant independent experience (e.g. coordinating events, recognized blog series)

☐ Expert-level experience (e.g. grants, conference talks, publications)

*Describe your experience with outreach in a sentence or two:

*Describe your typical audience (e.g. elementary students, prisoners, university freshmen) in a sentence or two:

*Describe your motivation for science outreach in a sentence or two:

Science Communication Survey

6 questions, approx. 45 minutes

Thank you for taking the time out of your day to respond to my survey! There is no time or word limit, so take as much or as little time as you would like, but it isn't meant to take more than an hour to complete the six questions. I just ask that you don't revise your responses once you move on to the next question.

I am immensely appreciative for your time and thoughtfulness, thank you!

*QUESTION 1 of 6

You are asked to write a guest post entitled "What you should know about science" for a nationally-read blog. Below, write an extended outline (an outline with enough information to convey your meaning) for the blog post you would submit. If applicable, describe the kinds of materials you would use to complete the article [e.g. research, resources].

*QUESTION 2 of 6

Describe your audience in the previous question. You can add anything at this point to clarify your response (who are they, what do they know, what is their experience with science, what resources do they have at their disposal, how will they seek and find information, etc.)

*QUESTION 3 of 6

Describe what is science literacy. What does it mean for someone to be scientifically literate?

*QUESTION 4 of 6

What is science?

* QUESTION 5 of 6

How does science differ from science literacy?

* QUESTION 6 of 6
What is literacy?

What does science literacy have in common with other types of literacy?

Science Communication Recruitment Scripts

List-serve Email

Graduate students in science and science education,

I'm a grad student in the College of Education (and Entomology department alumna!) conducting a survey about how scientists and science educators communicate science to the public. I am looking for graduate students in the sciences, science education, and related disciplines (such as philosophy of science) to participate in my survey. It should take less than an hour to complete, and while I cannot offer you any monetary compensation I can offer you the satisfaction of helping someone with her thesis ☺

You can use the following link to learn a bit more and to begin the survey itself:
https://illinois.edu/sb/sec/9767387

Thank you in advance for your time and consideration! Your responses will help immensely in understanding the impact of science communication on how the public understands and perceives science.

Feel free to ask any questions you may have, and I will be happy to answer!

Christina Silliman (Primary Investigator)
Sillima2@illinois.edu

Flier

I am looking for graduate students in the sciences, science education, and related disciplines (such as philosophy of science) to participate in a survey about how scientists and science educators communicate science to the public.

You can use the following link to learn a bit more and to begin the survey itself:
https://illinois.edu/sb/sec/9767387

Thank you in advance for your time and consideration! Your responses will help immensely in understanding the impact of science communication on how the public understands and perceives science.

Feel free to ask any questions you may have, and I will be happy to answer!

Christina Silliman (Primary Investigator)
Sillima2@illinois.edu

Social Media

Grad students in science, SciEd: participate in a survey about how you communicate science to the public! bit.ly/2e9bEsa sillima2@illinois.edu for details #SciComm

APPENDIX D: IRB APPROVAL

IRB EXEMPT APPROVAL

RPI Name: Barbara Hug
Project Title: Conceptions and Applications of Science Literacy in Science and Science Education Researchers
IRB #: 17319
Approval Date: November 15, 2016

Thank you for submitting the completed IRB application form and related materials. Your application was reviewed by the UIUC Office for the Protection of Research Subjects (OPRS). OPRS has determined that the research activities described in this application meet the criteria for exemption at 45CFR46.101(b)(1, 2). This message serves to supply OPRS approval for your IRB application.

Please contact OPRS if you plan to modify your project (change procedures, populations, consent letters, etc.). Otherwise you may conduct the human subjects research as approved for a period of five years. Exempt protocols will be closed and archived at the time of expiration. Researchers will be required to contact our office if the study will continue beyond five years.

(When appropriate add the following): Copies of the attached, date-stamped consent form(s) are to be used when obtaining informed consent.

We appreciate your conscientious adherence to the requirements of human subjects research. If you have any questions about the IRB process, or if you need assistance at any time, please feel free to contact me at OPRS, or visit our website at http://oprs.research.illinois.edu

Sincerely,

Michelle Lore

Michelle Lore
Human Subjects Research Specialist, Office for the Protection of Research Subjects
Attachment(s): Consent Document

c: Christina Silliman

Robb Lindgren

UNIVERSITY OF ILLINOIS

Science Communication Survey

Preview Mode - This Survey is Not Live

Form Validation Rules (test submission behaviors)

○ on ● off

Science Communication Consent Form

Who: Researchers at the University of Illinois at Urbana-Champaign (UIUC), College of Education

Research Interests: As science researchers we spend a lot of time and money on public outreach, and it is essential to understand the impact of these efforts. An aim of my research is to understand the connection between the ways we talk about science and public science literacy. Your responses will help immensely in understanding the impact of science communication on how the public understands science.

What: You will be responding to an open-ended survey with prompts about science and science communication. You may complete the survey at any time and place of your choosing, using an internet-enabled device. Taking part in this research study may not benefit you personally, but we [researchers] may learn new things that will help others. There are no costs to you for participating in this research

Risks: This research does not involve risks beyond those normally encountered online or in everyday life.

Duration: The time required to answer the survey questions would be approximately one hour. The survey will close after four weeks, after which you will not be able to complete the survey.

Participation: Participation is completely voluntary. You are not required to participate in the study if you do not wish to do so and you may decline to continue at any time. Further, you are free to withdraw your permission to participate at any time and for any reason. If you do participate, your responses will help broaden our understanding of how researchers engage with the public about science.

Survey Questions: You will be asked to respond to six questions about science and science communication. They are open-ended and responses should be based on your own opinions and experience.

Confidentiality: Any sharing or publication of the research results would occur only during educational presentations and with your specific consent. Your data will be coded with a participant number and not your name. No internal or published material will identify any of the participants by name, nor will it be made publically available online. If you prefer to take a physical copy of the survey, linking yourself with the research, you may request one by contacting the primary investigator. In general, we will not release any information about you, only the anonymized survey results. However, laws and university rules might require us to disclose information about you. For example, if required by laws or University Policy, study information may be seen or copied by the following people or groups: a) The university committee and office that reviews and approves research studies, the Institutional Review Board (IRB) and Office for Protection of Research Subjects, or b) University and state auditors, and Departments of the university responsible for oversight of research.

Contact Info: Please feel free to ask us any questions you may have. We will be happy to answer your questions.
Barbara Hug (Primary Investigator):
bhug@illinois.edu
Office Phone: 217-244-9090
Department of Curriculum & Instruction,
Room 302, 1310 South Sixth Street,
University of Illinois, Urbana-Champaign
If you have any questions about your rights as a participant in this study or any concerns or complaints, please contact the University of Illinois Institutional Review Board at 217-333-2670 or via email at irb@illinois.edu

Remember, your participation in this research is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University. If you decide to participate, you are free to withdraw at any time without affecting that relationship. Please print a copy of this consent form for your records, if you so desire.

* 1. I have read and understand the above consent form, I certify that I am 18 years old or older and, by checking the box below and clicking the next button to enter the survey, I indicate my willingness voluntarily take part in the study.

☐ I have read (or someone has read to me) the above information and I agree voluntarily to participate in this research.

Save and Finish Later...

Back page 1 of 8 Next

Survey provided by Web Services in Public Affairs | logout

University of Illinois at Urbana-Champaign
Institutional Review Board

Approved: 11-15-16
IRB #: 17319

APPENDIX E: SURVEY RESPONSES, EXPLICIT DEFINITIONS OF SL

ID	Responses to Survey Question 3 [what is SL]
P1	It means they know the scientific process and how to identify good science from junk science.
P2	Science literacy means understanding the process of science. What is a theory? How does evidence work? How are studies constructed to find the "right" answer?
P3	They would have to be able to read basic science or understand what science is and have an understanding of what each of the branches of science were. They would probably also need to be able to give examples of the branches of science and how that, in basic terms, has added to general human knowledge. If they can teach science to others, that is a good indicator that they know the material well.
P4	They are familiar with the scientific process/method - They are familiar with our methods of conveying information (through published journal articles) and confirming information (through repeating other groups' experiments) - They know where to find credible sources of scientific information - Advanced literacy: they know that when they read a published journal article, that the conclusions are one interpretation of the results. They know to be skeptical.
P5	Science is the inquiry-based approach to acquiring and organizing knowledge about the world around us, as characterized in Question 1. Literacy, in large part, is the ability to read and understand some written communication about a given topic. Thus, science literacy is the ability to read some written piece (here, listen to a talk works too) about a scientific topic and grasp its general meaning or directly-reported message (not necessarily its implications). Additional points: (1) General literacy also typically incorporates writing, although I'm not so sure that science literacy needs to include the ability to write about a scientific topic. (2) [Science] literacy is not black-and-white; in other words, it's not "you either have it or you don't". There are gradations. As a (scientific) example, one might understand a physics piece tackling F = m*a, but fall vastly short of understanding quantum mechanics. (3) As a corollary to the previous point, how material is presented certainly can affect an individual's scientific literacy. For example, a scientist doubling as pop sci writers often have a knack for making a complex topic more digestible.
P6	For someone to be scientifically literate means that they draw a distinction between faith and logic. How exactly that distinction is made may vary by individual--- but if someone explains everything in terms of faith, they are illiterate in the sense that they are unable to be logical.
P7	To be able to understand basic scientific concepts that people may encounter in life as outlined earlier.

P8	To be literate in science, in my opinion, is to have proficiency or understanding what is being talked about, as a baseline. I think it is the understanding that is key. Scientific literacy is like a minimum, easily attainable level for everyone. It is not an understanding of complex or very specific topics in science, it is simply that someone can understand enough to ask questions after being exposed to some scientific topic and can ask questions after to know more. It's not even to say that they have a interest in science, but more that the have curiosity to know more from the minimal amount that they know already. With that in mind, yeah, it is a baseline, but that baseline is ephemeral for a curious mind. Relatively speaking, that the more they investigate and inquire, the more their literacy changes for a given topic. Science is too broad to really understand all realms of it. I, for one, could not tell you anything about nuclear physics, but I do have a baseline understand of nuclear power and physics, so maybe I could survive if someone put a gun to my head. So yes, it is a baseline that is dependent upon the topic, the interest or curiosity, but really the understanding that a person has already.
P9	Well there are many different ways science literacy has been defined --much of it based on what facts and figures people know. Often a deficit mindset is enacted where we go to great lengths to show what people don't know as a way to demonstrate that scientific literacy is lacking. I do not think knowing the internal temperature of the earth or that lasers use light waves and not sound waves makes a person scientifically literate or not. Knowing facts and figures is one way that people can easily measure knowledge....but scientific literacy to me means knowing something about how science works and knowing how to apply scientific thinking or information in context--being scientifically literate to me means that someone knows how to use science information in the context of their lives in a way that is useful. For me science literacy is about the relevance of the information and how people can connect science facts, and processes' in their own lives. Feinstein labels this type of pursuit as creating "competent outsiders" to science. People don't have to become little scientists--but they do need to understand science in the context of their lives.....

APPENDIX F: ANALYSIS OF THEORETICAL SL COMPONENTS, BY INDIVIDUAL

Table 19 – Analysis of theoretical SL components in current study, by individual, SL

Super-Component	Component	P1	P2	P3	P4	P5	P6	P7	P8	P9
Foundational Literacy	Primary Discourse	*x*	*x*	**X**	*x*	**X**	*x*	*x*		
Scientific Enterprise - Surface	Content			**X**	*x*	**X***		**X**	**X**	**X**
	Terminology			*x*						
	Reasoning processes				*x*	**X**	**X**		*x*	
	Knowledge production	*x*		**X**		**X***			*x*	
	Language of science		*x*		*x*	*x*			**X**	
	Genres of science	**X**	**X**	*x*	**X**	**X***		*x*		
Scientific Enterprise – Deep	Nature of science (pragmatic)	**X**	**X**			**X***	**X**		*x*	*x*
	A way of knowing									
	Sociality is central to meaning		*x*		**X**					
	Never autonomous or neutral		*x*		**X**				*x*	
Linking Dimensions	History of science						*x*		*x*	
	Aesthetic qualities			*x*			*x*	*x*	**X**	
	Connection to other domains	*x*	*x*					*x*		*x*
	Relationship to technology									
Pragmatics	Impact on decision making in everyday life		*x*		*x*			*x*	*x*	**X**
	Science, technology, and society			*x*	*x*		*x*		*x*	*x*

Table 19 (cont.)

Critical Dimensions	Centrality of language and discourse				*x*	**X**			*x*	
	Transformational	*x*								*x?*
	Deep connection and/or understanding			*x?*	*x*					
Expert-Level	Philosophy of science (broad)									

Note: P5 wrote that SL was "as characterized in question 1"; ***X**** *represents this ambiguity*

Table 20 – Analysis of theoretical SL components in current study, by individual, Science

Super-Component	**Component**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**
Foundational Literacy	Primary Discourse									
Scientific Enterprise - Surface	Content			**X**	**X**	*x*		*x*	*x*	**X**
	Terminology									
	Reasoning processes	*x*		*x*	*x*	**X**	**X**	**X**	**X**	
	Knowledge production	*x*	**X**	*x*		*x*			*x*	
	Language of science									
	Genres of science	**X**	**X**	*x*	**X**	*x*		*x*	**X**	**X**
Scientific Enterprise – Deep	Nature of science (pragmatic)		*x*			*x*	**X**		*x*	**X**
	A way of knowing									
	Sociality is central to meaning		*x*		*x*					
	Never autonomous or neutral		*x*		*x*				*x*	
Linking Dimensions	History of science								*x*	
	Aesthetic qualities									
	Connection to other domains	*x*	*x*				**X**			*x*
	Relationship to technology									
Pragmatics	Impact on decision making in everyday life	**X**	*x*					*x*	*x*	*x*
	Science, technology, and society			*x*	*x*		*x*			*x*
Critical Dimensions	Centrality of language and discourse				*x*					
	Transformational	*x*							*x*	*x?*
	Deep connection and/or understanding									
Expert-Level	Philosophy of science (broad)									

Table 21 – Analysis of theoretical SL components in current study, by individual, Literacy

Super-Component	**Component**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**
Foundational Literacy	Primary Discourse	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Scientific Enterprise - Surface	Content									
	Terminology									
	Reasoning processes									
	Knowledge production									
	Language of science		**X**			*x?*				
	Genres of science									
Scientific Enterprise – Deep	Nature of science (pragmatic)									
	A way of knowing									
	Sociality is central to meaning									
	Never autonomous or neutral									
Linking Dimensions	History of science									
	Aesthetic qualities									
	Connection to other domains									
	Relationship to technology									
Pragmatics	Impact on decision making in everyday life									**X**
	Science, technology, and society									
Critical Dimensions	Centrality of language and discourse									
	Transformational									
	Deep connection and/or understanding									
Expert-Level	Philosophy of science (broad)									