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Jenny M. Dauer
University of Nebraska-Lincoln, U.S.A

Valentina Bravo Gaona
Utrecht University, Netherlands

Ralph Meulenbroeks
Utrecht University, Netherlands

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Vision II Scientific Literacy Assessment Instruments for Secondary Education: A Scoping Review

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Abstract

Scientific literacy is an organizing principle for K-16 education but is notoriously difficult to operationalize. This study provides a list of instruments that measure aspects of Vision II scientific literacy, or science for citizenship. Based on the definition of scientific literacy by the National Academies of Sciences, Engineering, and Medicine (NASEM), a scoping review was performed to identify assessments aimed at secondary education, specifically for Vision II aspects of scientific literacy: "Identifying and Judging Scientific Expertise," "Epistemic Knowledge," "Cultural Understanding of Science," and "Dispositions and Habits of Mind." Nineteen widely-cited instruments were found for secondary education levels, published after 1990 in the English language. Epistemic knowledge was assessed by 14 of them, cultural understanding of science in 12, dispositions and habits of mind in eight, and identifying and judging scientific expertise in four assessment tools. Only one tool measured all four of these aspects. Four assessment tools were framed around fully articulated specific socioscientific issues contexts, the rest were generalized. Areas of strength and deficit in evaluating success in achieving Vision II scientific literacy were identified, including the challenge of assessing scientific literacy at a community level, and trade-offs that exist around the degree of contextualization within the instrument.

Introduction

Scientific literacy has been an international organizing principle for K-16 science education for decades, and continues to be lifted up as an imperative educational outcome for organizing bodies such as the United Nations (Schneegans & Nair-Bedouelle, 2021), the European Union (Siarova et al., 2019), Organisation for Economic Co-operation and Development (OECD, 2019), the National Academies of Science Engineering and Mathematics of the United States (NASEM, 2016), American Association for the Advancement of Science (AAAS, Project 2061, 1993), and the Food and Agriculture Organization of the United Nations (FAO, Davies & Carol, 2017). However, reaching a consensus on how to define scientific literacy has proved to be elusive and (re-)conceptualizations have been many (e.g., DeBoer, 2000; Miller, 1983; Laugksch, 1999; Norris & Philipps, 2002; Roberts & Bybee, 2014). Even the terms "science literacy" versus "scientific literacy" have been debated or differentially preferred by different researchers, though many researchers use both terms synonymously (e.g., Roberts, 2007; Feinstein, 2011). Broadly speaking, a scientifically literate person can be understood to be someone with a general understanding of scientific processes who is able to meaningfully engage with scientific information in daily life. Scientific literacy centres on the personal relevance of science rather than preparation for specific scientific or technical careers.

The concept of scientific literacy has been referred to since the early 19th century, and increasingly since the 1950s, to describe the need for science understanding for non-scientists (Rudolph, 2023). The phrase has been used to galvanize various causes depending on the historical context, including societal support of government funding for research, and an understanding of the impact of science on society, and workforce/economic development (Rudolph, 2023). In the 1970s and 1980s the phrase was redefined by Miller (1983; 1987) in terms of general knowledge about basic scientific facts, scientific method and an appreciation of science’s social impact. DeBoer (2000) built on these ideas with nine wide-ranging educational goals, again broadening the term, with a focus on how views of scientific literacy might be used to inform educational reform. Focusing on the utility of science, Feinstein et al., (2013) defined scientifically literate individuals as those who recognize when science has some bearing on their needs and interests and can access and make sense of science to achieve their goals. More recently Roberts & Bybee (2014) created a now widely-used framework distinguishing between two foci of scientific literacy learning: Vision I and Vision II. Vision I is grounded purely in the products and processes of science and may be viewed as relevant mainly for those aspiring to become scientists (i.e., “science” literacy). In contrast, Vision II starts with situations with a scientific component that ordinary people encounter in every-day life, and is considered science for citizenship (i.e., “scientific” literacy).

Given its long history and varied definitions and purposes, “scientific literacy” has long been criticized as an umbrella concept defined in various and changing ways making it difficult to coalesce on specific competencies (Shamos 1995; DeBoer 2000; Roberts 2007; Yacoubian, 2018; Rudolph, 2023). While science educators, scientists and policy makers continue to use the concept of scientific literacy as a rallying cry, it remains difficult to operationalize. For researchers in science education, it is often unwieldy to navigate in terms of specific learning goals and measurement (Rudolph, 2023). Identifying tools to gauge student learning of scientific literacy knowledge and skills can be difficult, especially because of the all-encompassing and diffuse nature of its meaning.

In particular, Vision II skills of accessing and interpreting the science most relevant to individuals’ lives (Feinstein et al., 2013) despite its importance, is less frequently operationalized in measurement, and poses greater challenges for measurement (Romine et al., 2017). Vision I is more pervasive and frequently assessed, often in the form of recall of basic concepts and facts. Assessments purported to measure scientific literacy are often focused on Vision I, such as international measurements like PISA (e.g., OECD, 2019), and TIMSS (Mullis & Martin, 2017). There are also a wealth of assessments of knowledge or concept inventories of one or more specific science disciplines or science skills. Additionally, influential documents that drive assessment development are often highly focused on Vision I, such as the Next Generation Science Standards (NGSS, Lead States, 2013).

There is no widely-accepted assessment that educational researchers agree upon to evaluate individuals' changes in Vision II scientific literacy (in terms of students' ability to apply science to every-day life) (Roberts, 2007). This leaves educational researchers who are interested in students' Vision II scientific literacy without a clear road map. An overview of what tools are available for educational researchers to measure individual student Vision II scientific literacy learning gains can reveal how Vision II scientific literacy is currently operationalized in the field of science educational research, and may provide insight on the status of our understanding and promotion of this aspect of scientific literacy.

Vision II scientific literacy may pose significant opportunities and challenges for instrument development because it is necessarily highly embedded in situational contexts, such as science-relevant personal issues or socioscientific issues (SSI) such as environmental quality and societal health. SSI are societally and scientifically relevant topics that are multi-faceted, lack one clear solution, engage many stakeholders (Zeidler & Sadler, 2011) and are often embedded within individuals' daily life or personal experiences. These contextually-rich experiences may impact how students learn and how we assess them. Prior knowledge and experience influences learning and meaning making because context is intrinsically imbedded in complex cognitive networks, a concept supported by constructivist theory (Klassen 2006; Sánchez Tapia, 2020). To effectively apply their knowledge to challenges in different everyday life situations (Bransford et al., 2000; Bransford & Schwartz, 1999), individuals need to develop knowledge and abilities organized in a way that allows for quick retrieval. Assessing knowledge in a decontextualized fashion will not necessarily demonstrate if this knowledge has been integrated into long-term memory structures and can be readily accessed and used in a new situation, which creates inference and validity limitations for decontextualized instruments. On the other hand, contextualized assessments allow learners to demonstrate their ability to apply knowledge to the real world and everyday problems (Herman et al., 2018; Härtig et al., 2020), representing an important Vision II achievement. The degree to which assessments are generalized versus contextual in nature plays an important role in the meaning of the assessment, and is an important feature for scientific literacy researchers to attend to when considering assessment choice and research design.

As with any type of research to understand students' ability to apply scientific ideas to everyday life, some means of operationalizing Vision II scientific literacy is needed. Researchers may use any number of organizing frameworks, and due to lack of consensus any particular choice is vulnerable to criticism. However, without a framework it would be impossible to carry out a scoping review on assessment tools, the aim of this study. Therefore, we selected a framework based on the wide breadth of literature-based scientific literacy concepts it included, the NASEM (2016) report.

In addition, the report is a commonly cited and relatively recent scientific literacy framework based on a science education literature review by a large panel of experts. One of the core charges in assembling the NASEM report was to synthesize the consensus on metrics and assessments for science literacy (NASEM, 2016, p.2), which is a useful lens for this paper. The NASEM report reviews multiple definitions of scientific literacy in the literature and attempts to organizes the most salient concepts. It identifies seven aspects of both Vision I and Vison II scientific literacy that are considered common to most applications of the term (NASEM, 2016, pgs. 2-9 to 2-10) and are briefly described here:

(1) Foundational Literacy – fluency in the use of words, language, numbers and mathematics to interpret texts.
(2) Content Knowledge – textbook knowledge, or understanding a set of scientific terms, concepts and facts of a discipline.
(3) Understanding of Science Practices – understanding or achieving the skills of a scientist such as collecting and analyzing data.
(4) Identifying and Judging Scientific Expertise – making judgements about the expertise of scientists.
(5) Epistemic Knowledge – understanding how the procedures of science support the claims made by science, for example, understanding how uncertainty is managed in science processes and how the evaluative process of peer review sustains objectivity, understanding the strengths and limitations of the human enterprise of science.
(6) Cultural Understanding of Science – acknowledging the interrelationship of science and society and science and the humanities and recognizes science as a major human achievement.
(7) Dispositions and Habits of Mind – for example inquisitiveness, open-mindedness and a commitment to evidence.

The NASEM report also expanded the conception of scientific literacy by describing three levels of organization, individual (the most common scientific literacy focus of individuals' knowledge, skills, attitudes, behaviors or dispositions), community (how resources are distributed and organized so that community members can work collectively to their overall well-being and are empowered by science), and societal (either aggregate data of individuals or social structures). The NASEM report found that research on scientific literacy at the individual level has largely focused on assessing conceptual knowledge (Vision I).

Focus on the individual level limits our conceptual understanding of scientific literacy, especially given how literature reviewed in the report indicates a lack of a direct causal pathway between individuals' knowledge and their attitudes or behaviors. However, peoples' attitudinal or behavioral responses to science-related situations and ability to apply science in these situations is the crux of Vision II scientific literacy (NASEM, 2016) so it is unclear how well current conceptual knowledge-based scientific literacy instruments map to this concept. The field of science education needs to study how science education impacts individuals' attitudes or behaviors in everyday contexts as an assessment of Vision II scientific literacy achievement. However, as discussed above, Vision II assessments are fewer in number, may be difficult to identify, or contain important limitations.

In this study we consciously focus on the last four aspects of scientific literacy in the NASEM report, because they have the greatest alignment with Vision II and are less present in common assessments. Our research questions were: 1) *What are available and widely-used secondary education assessment instruments measuring concepts contained in the NASEM report's scientific literacy aspects 4 through 7? 2) What are the general parameters of these Vision II scientific literacy assessment instruments, including if they are situated within a SSI context?*

Providing science education researchers with an overview of reliable and validated instruments to navigate the complexity of the concept of (Vision I or Vision II) scientific literacy is no trivial endeavor, as there is an extraordinary number of results when searching for, e.g., "scientific literacy assessments," because of the wide use of the term, while on the other hand there is a "relatively limited array of metrics available for measuring scientific literacy" (NASEM, 2016, pg., 1-2). To illustrate, a recent systematic literature review on assessment tools for scientific literacy failed to unearth some of the more commonly used assessment tools (e.g., VASI, VNOS), as it fully relied on the search term "scientific literacy" (Coppi et al., 2023).

For these reasons, we chose to conduct a scoping review (rather than a systematic review) to synthesize the extent, range and nature of scientific literacy instruments. In our review we relied on Vision II scientific literacy concepts in the literature to methodically identify and describe relevant instruments regardless of the presence or absence of the "scientific literacy" phrase. We also consciously narrowed the scope of this study by considering instruments appropriate for the practical case of a researcher studying secondary students in classrooms. This allowed us to focus specifically on assessments that are appropriate for non-adult populations designed for educational contexts.

Methods

We used a scoping review which can be useful to map the range and nature of research in the field of interest, starting from landmark publications, and to identify possible gaps in the literature, without claiming to be fully systemic or exhaustive. In comparison to a systemic review focused on a well-defined question and a narrow range of search terms and quality indicators, scoping reviews address broad topics and are less likely to address very specific research questions, nor to assess the quality of included studies. Scoping reviews prove very useful in adequately answering research questions within a field that is as large and diverse as the field of scientific literacy (Arksey & O'Malley, 2002). We followed the recommended stages identified by Arksey & O'Malley (2002): 1) identifying the research question; 2) identifying relevant studies; 3) study selection; 4) charting the data; 5) collating, summarizing and reporting the results. We also followed a parallel and optional stage—a "consultation exercise" to inform and validate findings from the main scoping review, which involves asking other experts to review and provide insights on papers that may have been missed in our review process. In our case, we asked three experts in science education to review our list of assessments and provide additional assessments we may have missed.

We first identified relevant studies that fit scientific literacy aspects 4 through 7 (aligned with Vision II) in the NASEM report. We started from assessment tools that were known to us (e.g., VNOS, VASI, QuASSR), searched publications they cited and publications that cited them to arrive at related publications. Some publications conveniently contained lists with further assessment tools that were used as a starting point for further searches. To extend the search process, we specifically searched terms from the descriptions of aspects 4-7 in the NASEM report, with combinations such as "assessment." For searches we used Google Scholar, Web of Science and assessment databases such as Partnerships in Education and Resilience Assessment Tools in Informal STEM (PEAR-ATIS). Finding candidate papers was an iterative, snowballing process that occurred as new papers were discovered. In each case, our aim was to arrive at a sample that represents assessments that appear to be actively used in current research as an overview of the field.

The next stage was the selection of studies to be included. We used six criteria: (1) the assessment was STEM discipline-general, (2) the assessment in the study was applied in, or validated for, secondary education, (3) the assessment was published within the last 30 years, i.e., after 1990, to capture current research and more recent conceptions of scientific literacy, (4) the assessment was published in the English language, (5) the instrument was relatively widely cited (more than 10 citations for older publications), and (6) the instrument addressed at least one of the scientific literacy aspects 4 through 7 in the NASEM report.

The discussions to determine assessment inclusion took place during twenty, 1.5-hour meetings between the authors. The individual items of the assessments were scrutinized and compared to the wording in the definition of the aspects in the NASEM report. Several concrete examples illustrate our decision-making process. For example, PISA (OECD, 2019) was not included. Despite PISA being a widely-cited international framework for science literacy, we excluded it because its focus shifted to Vision I in more recent editions (Zetterqvist & Bach, 2023), and it is aimed at the societal level built to monitor national-level student status, and the assessments are not available to use for science education research. We excluded the Scientific Literacy Survey for College Preparedness in STEM (SLSCP-STEM) (Benjamin et al., 2017) after inspection of the items which were primarily focused on science professional identity, biology content knowledge and discipline-specific reasoning skills. The Science Process Skills Inventory (SPSI) was excluded because the items focused on knowledge of the research cycle, which is aspect 3 of the NASEM definition (Arnold & Bourdeau, 2009) and thus more aligned with Vision I. We note that the criteria to exclude these tests do not imply any quality judgment, rather less fit to our specific aim.

After the discussions sessions, we arrived at a total of 19 assessment instruments. We charted the data by describing the assessments, their validation and reliability checks, and the availability of the assessment items. Then, the level of context present in the items was discussed. Assessments were categorized as "light" context when items were generalized or non-specific. For example: “Science helps me to make sensible decisions,” (CARS assessment); and “Two students are asked if scientific investigations must always begin with a scientific question. One of the students says ‘yes’ while the other says ‘no.’ Whom do you agree with and why?” (VASI assessment). Assessments were coded as “full” context when items contained detailed descriptions of personal or socioscientific issues. An example is a part of the QuASSR-assessment which describes a fracking operation in a specific state in the US with the energy company employing scientists to investigate possible environmental damage and local residents teaming up with the Environmental Protection Agency to do the same. The description is about 300 words long and includes details such as the number of inhabitants, the revenues the energy company is expecting, the nature of the aquifer used in the fracking, etc.

Discussions between the authors were continued until full agreement was reached. In the final stage of the scoping review we collated, summarized, and report the results. In a consultation exercise, we asked three experts to review and provide insights on papers that we may have missed in our review process. Two experts were authors of commonly-used science literacy assessments that were included in our review, and one expert had recently conducted a systematic review of nature of science assessments. Two experts found no additional instruments. The third expert suggested three potential instruments based on a review of nature of science instruments, though after inspection none of the suggested instruments fit our specific Vision II-related criteria.

Results

The 19 assessment instruments that met the criteria and cover the NASEM aspects 4 through 7 were found (Table 1). Likert scales are used in over half of the assessment tools in the table (11/19), six tools rely on multiple choice questions, and five use open-ended questions. Only four assessments had “full” contexts. Almost all assessments include a description of the validation process, which usually is performed by (a combination of) expert review, field testing, think-aloud procedures, or Rasch item analysis. Note that some publications do mention validation but do not specify its nature and some do not mention the validation process. The last column indicates whether or not all the assessment items are part of the original article or located in a supplement to the article, otherwise items were available on a website or through contacting individuals.

Table 1. Assessment Tools of Aspects 4-7 of the NASEM Definition of Scientific Literacy as Selected during the Scoping Review

Assessment Tool	**Publication**	**Scientific literacy Aspect**				**Item**		**Testing reported**		**Full tool available in publication**
		4	**5**	**6**	**7**	**Type**	**Context**	**Validity**	**Reliability**	
Views on Science-Technology-Society (VOSTS)	Aikenhead & Ryan, 1992		✓	✓		MCQ	Light	Standards-based, think aloud		Yes
Scientific Habits of Mind Survey (SHOMS)	Çalik & Coll, 2012		✓	✓	✓	Likert	Light	FA	Cronbach	Yes
Epistemological Beliefs Assessment for Physical Science (EBABS)	Elby, Frederiksen, Schwartz, and White, 2002		✓	✓	✓	Likert, MCQ	Light	Think-aloud		Yes
Scientific literacy Assessment (SLA)	Fives et al., 2014		✓	✓		Likert, MCQ	Full	Expert review, Think aloud, FA	Cronbach	Yes

Test of scientific literacy skills (TOSLS)	Gormally et al., 2012	✓	✓			MCQ	Full	Expert review, test item analysis		Yes
Views About Sciences Survey (VASS)	Halloun, 1996		✓	✓		MCQ	Light	Yes		No
The Muenster Epistemic Trustworthiness Inventory (METI)	Hendriks et al., 2015	✓				Likert	Full	Expert review, EFA, CFA	Cronbach	Yes
Views of Nature of Science (VNOS)	Lederman et al., 2002		✓	✓		Open-ended	Light	Think aloud		Yes
Views about scientific inquiry (VASI)	Lederman, et al., 2014		✓			Open-ended	Light	Standards-based, Expert review	% agreement	Yes
Student Understanding of Science and Scientific Inquiry (SUSSI)	Liang, 2006		✓	✓		Likert and open-ended	Light	Standards-based, expert review, think aloud	Inter-rater reliability, Cronbach	Yes
Test of Science-Related Attitudes (TOSRA)	Long & Fraser, 2015			✓	✓	Likert	Light	Discriminant validity, field tests in intercultural contexts	Cronbach	Yes
Scientific Attitude Inventory: A Revision (SAI-II)	Moore & Foy, 1997				✓	Likert	Light	CFA, EFA, Expert review	Split-half, Cronbach	Yes
Global Scientific Literacy Questionnaire (GSLQ)	Mun et al., 2015		✓	✓	✓	Likert	Light	Expert review, EFA, CFA	Cronbach	Yes
Trust in Science and Scientist	Nadelson, 2014	✓	✓			Likert	Light	Field test	Cronbach	No

Inventory (TSSI)										
Critical Thinking in Everyday Life scale (CTEL)	Mincemoyer et al., 2001				✓	Likert	Light	Yes	Cronbach	Yes
Quantitative Assessment of Socio-Scientific Reasoning (QuASSR)	Romine, 2017	✓	✓	✓	✓	MCQ	Full	Rasch		Yes
Views of Scientific Inquiry (VOSI)	Schwartz, Lederman, & Lederman, 2008		✓			Open-ended	Light	Expert review, interviews after	Inter-rater reliability	No
Changes in Attitude about the Relevance of Science (CARS)	Siegel & Ranney, 2003			✓	✓	Likert	Light	Rasch	Cronbach	Yes
Epistemological Views Toward Science (EVTS)	Tsai & Liu, 2005		✓	✓		Likert	Light	Yes	Cronbach	Yes

Note: Aspect 4 - Identifying and Judging Appropriate Scientific Expertise; Aspect 5 - Epistemic Knowledge; Aspect 6 - Cultural Understanding of Science; Aspect 7 - Dispositions and Habits of Mind. MCQ: multiple choice questions, Generic: no context, Light: rudimentary context, Full: extensive case context, EFA/CFA: exploratory/confirmatory factor analysis, PCA: factor analysis, Cronbach: Cronbach's alpha calculation, Rasch: Rasch model analysis.

Discussion

Our main goal to was to list and describe the available secondary education assessment instruments measuring concepts contained in the NASEM report's Vision II scientific literacy aspects 4 through 7 through a scoping review. We found 19 instruments, which are a representation of the current, commonly-used and easily-accessible assessments that are appropriate for secondary education. The instruments in Table 1 provide a useful starting point for researchers aiming to measure the more elusive aspects of Vision II scientific literacy in secondary education, and gives insight into how our field currently operationalizes scientific literacy.

Summary of Assessments

Epistemic knowledge (scientific literacy aspect 5) was addressed by the majority of the tools (14 out of 19). The NASEM report's dimension of epistemic knowledge connects with the concepts of nature of science (NOS) understanding, which can be defined as the epistemology of science or the values and beliefs inherent in the development of scientific knowledge (Lederman, 1992). The instruments we list cover a large range of subconstructs related to science epistemology and NOS. There have been many instruments developed to measure students NOS understanding (Sobotka, 2023), though in recent years fewer new instruments have been developed, with most NOS research heavily reliant on the VNOS questionnaire (Abd-El-Khalick & Lederman, 2023). There were three instruments used between 1954 and 2012 that account for more than 50% of NOS assessments – Test on Understanding Science (TOUS) (Cooley & Klopfer, 1961) and View of Science-Technology-Society (VOSTS) (Aikenhead & Ryan, 1992) and the VNOS (Lederman et al., 2002; Abd-El-Khalick & Lederman, 2023). The VNOS is the instrument by far most used by researchers (Abd-El-Khalick & Lederman, 2023), and meets our criteria for being a more recent instrument. Epistemic knowledge is a relatively well-developed area of research with easily identifiable current measurement tools in contrast to the other NASEM Vision II scientific literacy aspects.

Cultural understanding of science (scientific literacy aspect 6) was present in 12 out of 19 instruments. The instruments that devote the majority of items to cultural understanding of science include VOSTS (particularly as it relates to technology policy and development, and technology's relationship to science and society), CARS (the relevance of science to everyday life and to decision making about topics such as health and the environment), TOSRA (the social implications of science and the normality of scientists), and EVTS (social negotiation of science, scientists' objectivity, and the culture-dependent nature of the development of scientific knowledge). In many cases, cultural understanding of science concepts were embedded in assessments focused on epistemic understanding of science. For example, the VASS instrument has one dimension of personal relevance to life, the VNOS and SUSSI instruments have one aspect related to understanding social and cultural influences on science, the GSLQ includes one dimension on science as a human endeavor, and the SLA has one dimension that encapsulates multiple science and society concepts including applying scientific conclusions to daily life, identifying scientific issues underlying policy decisions and understanding the role of science in decision making.

Cultural understanding of science has always been at the forefront of ideas about scientific literacy (e.g., Feinstein et al. 2013). The need for this aspect of scientific literacy has become especially apparent since the COVID pandemic and the growing concern about the "post-truth" era including massive spread and acceptance of misinformation, denial of scientific claims, politization of scientific information and its impact on large-scale policies (e.g., Barzilai & Chinn, 2020; Sharon & Baram-Tsabari 2020; Fackler, 2022; Osborne et al., 2022; Sinatra & Hofer, 2021). This has led to an increased awareness for the need to incorporate social dimensions into the complexities of science-related decision-making (e.g., Herman et al., 2022; Lesnefsky et al, 2023), particularly when issues are controversial or politicized.

The NASEM report's description of cultural understanding of science focuses on appreciating the beauty and wonder of science, recognizing the achievements of science and acknowledging the interrelationship between science and society. We suggest what is missing may be a clearer crystallization of the complexity of "science acceptance," (the opposite of "science denial") that manifests itself in different ways across complicated contexts. The aspects of scientific literacy skills needed to navigate this complex post-truth environment, e.g., being able to identify misinformation, may actually intersect multiple NASEM scientific literacy aspects (Sharon & Baram-Tsabari, 2020). Indeed, new instruments may need to be developed that hone in on these particular challenges of our current times.

Dispositions and habits of mind (scientific literacy aspect 7) was the focus of eight instruments that assesses (mis)trust of authorities, open mindedness, skepticism, rationality, suspension of belief, objectivity and curiosity—the Scientific Habits Of Mind Survey (SHOMS) being an explicit example. A large part of the QSLQ instrument is about habits of mind (communication and collaboration, systematic thinking and information management) and character and values (ecological worldview, social and moral compassion and socioscientific accountability). The CTEL instrument was included because of its focus on critical thinking which can be considered a science disposition or habit of mind and a key component of scientific literacy (Almeida et al., 2023). The TOSRA included items about acceptance of scientific inquiry as a way of thought and the adoption of scientific attitudes. Two instruments had items related to effort and persistence in science learning (EBAB, SAI-II). And the QuASSR instrument embeds items within a SSI context to assesses the ability of students to recognize the inherent complexity of SSIs, examine issues from multiple perspectives, appreciate that SSIs are subject to ongoing inquiry, and examine potentially biased information with scepticism. More instruments may be available related to dispositions if the concept is broadened to include constructs like self-efficacy, metacognition and science identity, but we chose to adhere to our more narrow definition.

Only four tools assess aspect 4 (identifying and judging scientific expertise). This relative scarcity can result in significant limitations for educational research, especially given recent post-pandemic interest in supporting students' ability to evaluate scientific information and identifying scientific expertise (e.g., Osborne et al., 2022; Klaver et al., 2022). The items that do assess this dimension do not appear to be overly cumbersome and are all assessed with either MCQ or Likert items. Interestingly, just one assessment tool is specifically devoted to just aspect 4: the Muenster Epistemic Trustworthiness Inventory (METI).

We targeted assessments that were focused on the individual level of Vision II scientific literacy, with the frame of what might be useful to an educational researcher. However, the NASEM (2016) report calls to action the need for research using an expanded definition of scientific literacy across individual, community and societal levels, especially given that these three levels are intimately connected and affect one another. Conspicuously absent from field of science education research are assessments at the intermediate, community level, which would reveal if a community has sufficient shared resources distributed in a way that the varying abilities of community members work in concert to contribute to the community's overall well-being (NASEM, 2016, p. 73).

While some of the research to detect community-level scientific literacy may fall into the realm of sociology rather than science education, there are threads of science education research where notable assessment tools have been developed to understand how individual students are likely to act on topics tied to science in their communities. For example, the Predictors of Science Civic Engagement (PSCE) is a survey instrument to measure self-report attitudes, knowledge and intention to engage with their communities using their science skills (Alam et al., 2022). And the Self Perceived Action Competence for Sustainability Questionnaire (SPACS-Q) measures self-report knowledge of action possibilities, confidence in one's own influence, and willingness to act regarding sustainable development (Olsson et al., 2020). These types of instruments provide ideas for how to connect individual level assessments to community level actions and behaviors, filling a need for broader measurement concepts in scientific literacy. Ironically, these assessments do not necessarily fall cleanly into the NASEM report's scientific literacy aspects.

Research that falls within NASEM's community-level scientific literacy may expand beyond Vision II concepts. Preparing students to navigate and shape society is likely more aligned with Sjöström & Eilks' (2018) proposed addition of Vision III scientific literacy—emphasizing philosophical values, politicization and critical global citizenship education. Despite the concept of scientific literacy developing from a historical and current interest in developing individuals' preparation to contribute meaningfully to science-related civic issues (Shen, 1975; Sjöström & Eilks, 2018; Rudolph 2023), major gaps in research along these lines exist. For example, our field has not coalesced around a set of student characteristics that predict behavior or action based on evidence. To operationalize Vision III or community level scientific literacy more research is needed that bridges classroom experiences with behavior and decision making outside of the classroom walls.

Contextualization of Assessments

We also characterized the degree to which the instruments we found were embedded within a specific context. Only four assessment instruments, TOSLS (Gormally et al, 2017), SLA (Fives 2014), QUASSR (Romine et al., 2017) and the METI (Hendricks 2015) had detailed personal or SSI context. The QuASSR has the most in-depth context, with several paragraphs worth of detail describing a situation and stakeholders involved in making a decision, with a set of items for each SSI context. In contrast, the TOSLS relies on one real-world context for each item that varies in detail though including a screenshot of a websites, graphs of blood pressure or meat consumption data, questions set in colon cancer screening or caffeine content of beverages. The SLA instrument also has a unique context for each item; most items are a personal everyday context that involves scientific approaches (measuring heart rates after jumping jacks, designing a paper airplane, the school lunch schedule, etc.) and a few items may be considered SSI contexts (a mysterious illness in a town, annual car crashes on different highway types, average number of cavities per person in countries with various health education).

The METI assessment items are contextualized in the sense that respondents are asked to read a fictitious science blog entry (neuroenhancement, migraines and distractions), then give Likert-scale ratings of the science blog writer based on antonym word pairs (such as competent—incompetent). The rest of the assessments we found use abstract contexts ("scientists") or relate to a classroom context. Given that Vision II scientific literacy is based in applying knowledge and skills to the real world and everyday problems, the few context-rich instruments we were able to find point to a major need for the science education field—the development of assessments that are contextualized and are aimed at assessing students' abilities to transfer their learning to meaningful contexts. Assessments in the context of complex SSI require careful design considerations, including potential compromises and simplifications needed in the design (e.g., Kirk et al., 2024).

In general, more studies are needed to understand the benefits and limitations of contextualized assessment instruments. A limitation of contextualized assessments is that the performance of a particular task in a particular setting often does not generalize well to the performance of a similar task in another setting (Chi, Feltovich & Glaser, 1981), so contextualized assessments may lack in generalizability or even validity depending on the choice of context. For example, familiarity with the scenario in an assessment may influence student performance (Härtig et al., 2020), and researchers have observed that different context scenarios on otherwise isometric items produce different reasoning patterns both across science disciplines (Nehm & Ha, 2011; DiSessa & Sherin, 1998; Chu et al., 2009) and within SSI (Romine et al., 2020). In research of personal epistemologies, quantitative studies have shown poor reliability, partly due to the specificity of students' epistemic reasoning across disciplinary contexts and domains (Sinatra & Chinn, 2012; Greene & Yu, 2014), and it is possible that other Vision II scientific literacy constructs may similarly vary across disciplinary contexts or scenarios. Importantly, the trade-offs surrounding generalized versus contextual assessment instruments are important features that can influence the validity, meaning and usefulness of an instrument and must be carefully considered.

Selecting an Assessment Tool for Scientific Literacy

Returning to our initial aim, a hypothetical researcher might ask—which tool shall I use to measure Vision II scientific literacy? As so often in research, the answer is—it depends. First, our list is not comprehensive in that it focused exclusively on four aspects of the NASEM (2016) definition of scientific literacy that are closely related to Vision II scientific literacy. However, a strong case can be made for the importance of Vision II scientific literacy for young adults on the brink of contributing to society in adulthood, as has been done by many authors (e.g., Roberts & Bybee, 2014; Yacoubian, 2018; Artiery, 2016). In that case, we argue that Table 1 is a valid starting point for selecting assessment instruments.

Apart from the researcher's specific goals, there are other considerations. For example, we have already discussed how capturing Vision II learning may require assessments that use SSI contexts to more authentically gauge students' navigating these complex issues, though the availability of fully contextualized assessments is limited. Almost all of the assessments we found were Likert scales or MCQ, so fairly easy and quick to score and analyze. In contrast, open-ended response instruments are notoriously difficult and time-consuming to code, but may be more suited to fine-grained insight in students' reasoning. Though in the instruments we found, this format was primarily limited to assessments of students' nature of science.

In sum, we consider Table 1 an invitation for researchers to consider the multifaceted nature of the Vision II scientific literacy concept, and navigate among the more common assessments used to document student status or learning. Our scoping review reveals, and the NASEM report concurs (p. 36), that the development of measurements of scientific literacy have not evolved at the same pace as the definitions of scientific literacy, leaving the field with a concept that cannot yet be fully assessed. Given the multiple complex facets of scientific literacy, it is likely impossible to design a single assessment that sufficiently captures Vision II scientific literacy of students. Even assessments like the QuASSR that touched on all four aspects of Vision II scientific literacy is not necessarily comprehensive within each of the aspects. Since Vision II scientific literacy is highly contextualized, meant to describe the ways that science fits into personal and societal situations, it may be more productive for the field to better understand latent constructs that we are attempting to assess, how these constructs interface with learning in classrooms and what meaning they hold to students outside of the classroom.

Scoping Review Approach to Finding Scientific Literacy Assessment Tools

The scoping review approach allowed us to adhere to important conceptual aspects of scientific literacy and arrive at a relatively compact yet representative set of results. Many of the tools presented in Table 1 would not have been found if "scientific literacy" was a strict search term, for example we found instruments that were not presented in a recent systematic review on the same subject (Coppi et al., 2023), and yet all the tools in Table 1 assess one or more aspects of scientific literacy as defined in the NASEM report. A limitation of the scoping review approach is that our results cannot be categorized as exhaustive. Another limitation of our study is that to structure our findings, we focused exclusively on four aspects of a well-known (but not universally accepted) definition of scientific literacy by an established Western institution; using another scientific literacy framework could substantially change the content of the table.

Conclusion

Scientific literacy has seen many conceptualizations over the decades, and it continues to appeal to policy-makers and researchers alike as a key aim of science education. Scientific literacy has been notoriously difficult to define and definitions have shifted over the years. Early definitions mainly focused on foundational literacy, domain-specific content knowledge, and basic knowledge of how science works, e.g., the research cycle and the design of scientific experiments (e.g., Miller, 1983). These aspects are essential for those who aspire to become scientists (i.e., Vision I), and they have the advantage of being relatively easily assessed by standardized testing.

From the 1970's onwards the focus shifted to explicitly include the interaction between science and society and this eventually evolved into SSI being used as a way to assess other aspects of scientific literacy under the umbrella term of Vision II. Being able to gauge the quality of scientific expertise, being aware of the interactions between science and society, adopting a scientific mindset in major discussions, and understanding the advantages and limitations of scientific knowledge (all Vision II), are important for *all* citizens and not just for those relatively few who are aspiring to become scientists themselves. This study has compiled a list of assessments specifically directed at aspects of Vision II scientific literacy, that have for the most part been adequately validated and are readily available. This list of assessments furnishes a set of tools for researchers, and reveals areas of strength and deficit in comprehensively evaluating success in achieving Vision II scientific literacy.

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Author Information

Jenny M. Dauer

https://orcid.org/0000-0002-1373-8851

School of Natural Resources

University of Nebraska-Lincoln

3310 Holdrege Street

Lincoln Nebraska,68583-0961

U.S.A

Contact e-mail: *jenny.dauer@unl.edu*

Valentina Bravo Gaona

https://orcid.org/0009-0002-3628-2399

Freudenthal Institute

Utrecht University

Buys Ballotgebouw

Princetonplein 5

3584 CC Utrecht

Netherlands

Ralph Meulenbroeks

https://orcid.org/0000-0001-6614-9156

Freudenthal Institute

Utrecht University

Buys Ballotgebouw

Princetonplein 5

3584 CC Utrecht

Netherlands