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Conception of scientific literacy in the development of scientific literacy assessment tools: a systematic theoretical review

Maya Istyadji[1], Sauqina[2]

[1]*Faculty of TeacherTraining and Education,Universtas Lambung Mangkurat, Indonesia, maya_kimia@ulm.ac.id ,ORCID ID:* 0000-0001-5690-8489,
[2]*Faculty of TeacherTraining and Education, Universtas Lambung Mangkurat, Indonesia, sauqina@ulm.ac.id, ORCID ID:* 0000-0002-9301-9602

ABSTRACT
Scientific literacy has become the goal of science education throughout the world. To assess scientific literacy, the development of a scientific literacy instrument is imperative. Several scientific literacy instruments have been created, such as those for the Programme for International Student Assessment (PISA) and Project 61 for Science for All America. In this study, the authors conducted a systematic literature reviewof journal articles that report on the development of instruments to measure scientific literacy. This study used Publish or Perish 7 software to study all related articles from the SCOPUS database using keywords related to scientific literacy instrument assessment. The result shows that of 290 articles there were 46 articles that developed scientific literacy instruments and 43 articles that used at least one framework to create scientific literacy instruments. This study found 12 frameworks that had been used to develop scientific literacy instruments. However, the authors also found an article that did not use any framework to create a scientific literacy instrument. In this article, the authors discuss the trend of scientific literacy instrument development and its framework, how the framework has been used, and possibilities for future studies regarding the development of scientific literacy instruments.

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Introduction

Studies and discourse regarding scientific literacy have been around since the 1950s (e.g., Hurd, 1958. Recalling the use of science in major issues such as during the second world war (Miller, 1983), industrial automation and health policies (Hurd, 1958), it has been argued that it is necessary for society to actually understand how science and technology as its product would affect how a democratic society makes decisionsin matters related to these(Millar, 1997). However, over all this time, the term itself has rarely been defined while having grown into a multifaceted concept with numerous aspects based on expert evaluation (Holbrook & Rannikmae, 2009). For example, as early as 1983, Miller argued that other than two aspects of scientific literacy - to be able to read and write (Hurd, 1958) and to be cognisant of the science itself - there needs to be a third aspect: awareness of the impact of science on society Holbrook &Rannikmae have listed several names and organisation that haveelaborated on the definition of scientific literacy but which have led to confusion as to its exact meaning. Regardless, its main idea remains centred on an individual's ability to understand science and how to 'do science', and the relations of these with other attributes, such as higher order thinking skills, certain attitudes toward science, and the ability to connect science with other disciplines and endeavour (Holbrook & Rannikmae, 2009).

Several instruments to measure scientific literacy have been created, such as that created by the Organisation for Economic Co-operation and Development (OECD) under the auspices of theProgramme for International Student Assessment (PISA) (OECD, 2009b, 2013, 2017, 2019). PISA has been measuring scientific literacy since 2006 using an instrument based on the concept of scientific literacy that has been changing ever since (OECD, 2017).

Ten years earlier,one of the early instruments created to measure scientific literacy was created by Laugksch and Spargo for the Science for All Americans projects (SFAA; Laugksch & Spargo, 1996). When the frameworks underpinning the instruments are compared, it is evident that there are differences between the two constructs. Considering that there have been several instruments created to measure scientific literacy, the authors aimed to systematically review the literature about the frameworks used for the development of scientific literacy instruments throughout the world and made an overview of those frameworks in order to ascertain how recognised experts in scientific literacy decide on which aspects of scientific literacy should be taken and left when they have created a functional tool to measure scientific literacy. To compare it between one other surely could help understand which aspect that most experts argued could be observed, and how to observe it. By exploring the known article that reports on the development of scientific literacy instrument, a general overview of the development process could guide future scientific literacy instrument development attempts.

Scientific Literacy and Instrument Development

The concept of scientific literacy has become internationally acknowledged as the goal of contemporary education (Laugksch, 2000). However, despite enjoying such a high profile, there have been competing conceptions about the nature of scientific literacy. In the early eighties, Miller (1983) postulated that scientific literacy consisted of threedimensions: awareness of the norms and methods of science, cognitive science knowledge, and attitudes towardsscience. Later, Shamos (1995) proposed that scientific literacy operated at threelevels: cultural scientific literacy, functional scientific literacy, and true scientific literacy. True scientific literacy is the highest level that is most difficult to attain because it is a level where an individual understands and is aware of scientific theories, knowledgeable about the ontological and epistemological nature of science, and is appreciative of the whole enterprise.

OECD (2019) has defined scientific literacy with reference to three key competencies:explaining phenomena scientifically, evaluating and designing scientific inquiry, and interpreting data and evidence scientifically. There is confusion about its exact meaning (Holbrook & Rannikmae, 2009). Yet, it does not cease the public interest to achieve scientific literacy as the goal of science education (Roberts, 2007).

Roberts (2007) argued that when discussing scientific literacy, one must also consider the "continuing political and intellectual tension that has always been inherent in science education" (p. 729). The current discussion on scientific literacy reflects two different visions, which he called Vision I and Vision II. Vision I invokes one's interaction with the products of scienceThis science is associated with what has been taught in school. Vision II alludes to one's interaction with science knowledge that is commonly encountered as a citizen. These visions give rise to competitive views about school science. Is its purpose to teach science knowledge that is necessary to function as citizens or science knowledge that could equip a person to become a future scientist (Robert, 2007)?.Not knowing the answer to this question could make it difficult to come up with a consistent and relevant conception of scientific literacy.

Given uncertainties surrounding the term, there have even been attempts to remove science literacy from the goals of school science education (Fensham, 2008).However, it persisted. One of the reasonswas the OECD makingworldwide attempts to assess 15-year-old school pupils' scientific literacy every three years (Holbrook & Rannikmae, 2009). Many countries started to adopt scientific literacy as an indicator to assess whether a country's education system has been successful (Kemendikbud, 2017; O'Grady &Houme, 2015; OECD, 2019c). Hence, developing a scientific literacy instrument as a tool to measure scientific literacy become a necessity in many parts of the world(Miller, 1983; Naganuma, 2017; Vogelzang et al., 2020).

A functional assessment instrument tool requires the instrument developer to consider validity and reliability aspects. Validity in terms of anassessment instrument is the degree to "which it is possible to measure an attribute by using a test" (Newton and Shaw, 2014;12)while reliability "denotes the consistency of an assessment's results when the assessment procedure is repeated on a population of individuals or groups"(Newton and Shaw, 2014; 12). The interaction between the two often requires the instrument developer to find a compromise between validity or reliability. The concept of dependability was proposed as "the extent to which reliability is optimized while ensuring validity" (Harlen, 2005). To achieve it, instrument developers must make judgment and take consideration of which aspect must be compromised to ensure that a test is valid while still be reliable enough to be used for large studies For a high stakes test, it often argued that some assessment instruments might have to compromise the validity of the test construct for the sake of reliability (Black, 2004). However, when an instrument is developed academically, such situation is expected to be avoided as thedeveloper go to some lengths to explain and justify why certain decisions were made in the process of developing the said instrument, and ensuring peer review process were also carried out to review this formulation. This is why the authors of this study conducted a systematic review of published journal articles which reported the efforts in creating a framework for measuring scientific literacy.

Method

The authors conducted a systematic review to examine studies that reported on the development of scientific literacy instrument. The steps for the systematic review of relevant literature followedthe 4-step model of Cronin, Ryan, and Coughlan (2008) 1) Selecting a review topic, 2) Searching the literature, 3) Analysing and synthesising literature, and 4) Writing the review. To conduct the systematic review, the authors used two applications: 1) Publish or Perish 7; and 2) Zotero (Ver.5) I don't know these and I should imagine I would not be the only one. Explain what they are and why you chose them (Hudha et al., 2019).

The author used the SCOPUS database for the search. This database routinely reportsquality indicators such as journal publication consistency, citation rank, and peer review quality(Scopus, 2022). A total of 290 items was yielded by the search. Table. 1 shows keywords used in SCOPUS search and number of articles identified

Table 1

Keywords Used in SCOPUS Search and Number of Articles Identified

No	Keywords	Result yielded (article)
1	"scientific literacy" "measurement" "development"	21
2	"scientific literacy" "assessment" "development"	109
3	"scientific literacy" "test" "development"	103
4	"scientific literacy" "instrument" "development"	57
	Total	290

The results were exported in the form of .RIS files and then exported to the Zotero (ver. 5) application to be combined. Using Zotero the author refined the search results. Zotero identified which of those titles are in the form of book and which are in form of article. Zotero also sorts the article alphabetically from A to Z. From the automatic sorting, the author decided refine the search results by removing all books included within the list of items in search result, and removing identical articles identified by the name of the authors and title. Books are removed from the list because this study is focused on gathering information that is based on empirical studies that has been peer reviewed by the academic community before being published .

After the automatic sorting, a manual examination of each article was carried out by the authors. They read the abstract and decided whether the paper was relevant by seeing whether the article discusses creating any instrument to assess scientific literacy or assessing about scientific literacy. Relevance criteria used were:

1. The article must indicate that the author created an instrument to assess scientific literacy for the study reported in the article.
2. The article specifically uses the term "scientific literacy" to refer to the instrument created in the study.

Table 2 presents the refinement of the search result.

Table 2

Remained Article After Removal Process

Steps	Removal process	Article remained
1	Combination of all search result	290
2	Removing books	287
3	Removing similar articles	215
4	Removing irrelevant articles	46
5	Removing inaccessible article	43

The list of reviewed articles and excluded articles could be seen in Appendix A. Hence the authors only reviewed 43 articles ("final list".) The authors paid particular attention to the framework and the assessment instruments used.

The review process of the article is by reading the complete article and locating the part that explains scientific literacy instrument development. The examined aspects are the framework used, the assessment type of instrument, the country of where the research was conducted, and the general context of instrument implementation. As the fourth step, the result of the review is reported in the next sections. As a reliability measure, both author separately sorted the article manually, and then negotiate both list to reach agreement on which article should be included or excluded.

Results and Discussion

From our systematic review, it transpired that the earliest study that explicitly stated that it focused on the development of "scientific literacy instruments" could be found in 1991 reported on by Laugksch and Spargo in 1996. Laugksch and Spargoreported on the reformulation of the *Science for AllAmerica* (SFAA) scientific literacy goals and developed pool items to create an assessment instrument (Laugksch & Spargo, 1996). The framework of scientific literacy that they used was adapted from Miller 1983 paper, Scientific Literacy: A Conceptual and Empirical Review (Miller, 1983).Scientific literacy was measured from the perspective of three constitutive dimension: the norms and methods of science, cognitive science knowledge, and attitudes towards organized science.

This does not mean that no previous studies have discussed scientific literacy instruments. For exampleBaker & Piburn (1991)wrote an article called "Process skills acquisition, cognitive growth, and attitude change of ninth-grade students in a scientific literacy course." However, the instrument they used to assess scientific literacy was a combination of assessment instruments, including a psychological test to assess cognitive ability, attitude, and skills, and a logical operator test.

Nine years later, the second article discussing the development of scientific literacy instrumentswas from Chang and Chiu (2005), who also developed an instrument to measure scientific literacy of the 9th-grade junior high school pupils with reference to the Taiwan Ministry of Education scientific literacy framework of 1998.

The third article was published in 2007 authored by Bybee, McCrae, and Laurie (2009). This article reports the process of developing the PISA 2006 scientific literacy framework, and the development of the instrument based on the framework, while also reporting on the result of the assessment of OECD countries' scientific literacy results based on PISA 2016.

In 2012 and 2014, Gormally, Brickman and Lutz (2012) and Fives, Huebner and Birnbaum (2014) developed their own framework to create scientific literacy instruments. They both reviewed previous definitions and works on scientific literacy and then constructedtheir own distinctive frameworks. Gormally et al.'s instrument is the Test of Scientific Literacy Skills (TOSLS) while Fives et al.'s instrument is called the Scientific Literacy Assessment (SLA). Both studies were conducted in the US.

In 2015, a different approach to evaluate scientific literacy was proffered by Tomas and Ritchie (2015). They reported on the challenge of assessing the scientific literacy of year 9 pupils (13-14 years old) in a writing-to-learn context. Initially, they tried to adopt the SLA framework for scientific literacy but they decided that it was not nuanced enough for the task they gave to the research subjects, which was writing a story about socio-scientific phenomena in Biology from an actual event. They constructed a marking key based on the task's requirements with three levels of story comprehension. However, this study did not construct any scientific literacy framework for the assessment instrument.

In 2017 there were severalreports about instruments being developed to measure scientific literacy. It was about this year that the report on context of scientific literacy assessment become more specific. For example, Benjamin et al. (2017) created an instrument to measure the preparedness of prospective undergraduate or college students applying for STEM majors in the US. Naganuma(2017) developed an instrument to measure the civic scientific literacy, scientific literacy that views science from the perpective of social life,of Japanese people above 20 years old. This is unlike previous scientific literacy assessment attempts, which focused on school pupils who attended formal science education.

It was also in 2017 that the approach to develop scientific literacy assessment changed. Although Benjamin et al. were still using a similar approach to their predecessors, where they constructed a scientific literacy framework based on combining scientific literacy definitions, other authors approached it differently. For example, although Naganuma reviewed many definitions of scientific literacy, he chose to use the PISA 2006 scientific literacy framework as the basis of his instrument development. However, he made adjustments by removing one competency and replacing it with other competencies to serve the purpose of his research.

A similar approach could also be found in Rubini, Ardianto and Pursitasari(2017) and Sinaga, Kaniawati and Setiawan(2017), who also used the PISA 2006 scientific literacy framework, but only usedonly maximum of two from four aspects of the original framework. The instrument format used by Sinaga et al. (2017) was also different from what was described in the PISA 2006 scientific literacy framework. Sinaga et al. (2017) only used the option-response format rather than the constructed-response format as used bythe PISA 2006 scientific literacy assessment instrument.

Another difference between Benjamin et al. and Naganuma articles with those of Rubini, et al. and Sinagaet. al. (2017) is that the latter's principal research goal was not to develop a scientific literacy instrument. Rubiniet al. created an instrument to map the scientific literacy level of science teachers to develop a professional development model for them. Sinaga, et al. (2017) created the instrument to assess whether pupils' scientific literacy improved if they studied using a better-designed science textbook.

Within 2017-2021, more articles explicitly stated that a scientific literacy instrument had been created in their study. However, no more articles created scientific literacy frameworks the way researchers before 2015 had done. Most articles created a scientific literacy instrument based on an already created framework, such as PISA, TOSLS and SLA. Other than that, a few authors created aninstrument that was not based on any scientific literacy framework like Tomas and Ritchie (2015).

The authors found that there were several approaches that researchers use to develop a scientific literacy instrument for the entire sample of 43 papers. In summary, there are four framework development approaches:

A) Developing a scientific literacy instrument based on a framework developed by conceptualising scientific literacy through the definition of scientific literacy from expert commentators or field observation, or a combination of both. Included in this group are mostly frameworks that were created before 2018.
B) Developing a scientific literacy instrument by adopting a framework from studies in approach A.
C) Developing a scientific literacy instrument by using the framework arising in approach A, but with slight modifications, such as combining or reducing the framework's components, while still keeping some part of the construct intact.
D) Developing a scientific literacy instrument without using any framework.

Instruments from Scientific Literacy Framework: Development, Adoption and Adaptation

This study found that nine frameworks had been used in the process of creating scientific literacy instruments. These frameworks had been fully adopted, partially modified, or combined and reconstructed into a new framework depending on the context of the instruments' creation. The list of the scientific literacy framework could be seen in Table 3. Table 4 shows a newly developed scientific literacy framework, adapted from some of the framework in Table 3.

Table 3

Frameworks used to Create aScientific Literacy Instrument

	Frameworks	Framework development approach*	Used by other authors			Total of article which used the framework
			Fully adopted	Adapted	insufficient information	
1	PISA 2015**	A	0	8	2	10
2	Test of Scientific Literacy Skills (TSOLS) (Gormally et al., 2012)	A	2	2	1	5
3	Scientific Literacy Assessment (SLA) (Fives et al.)	A	0	1	0	1
4	PISA 2006 (Bybee et al.)	A	0	1	0	1
5	PISA 2012**	A	0	1	0	1
6	Pan-Canadian Assessment Program 2013**	A	1	0	0	1
7	Miller	A	0	1	0	1
8	Taiwan Ministry of Education**	Not provided	1	0	0	1
9	Standard Observed Learning Outcomes (SOLO) taxonomy**	A	0	1	0	1

Note. *Framework Development Approaches are divided into 4 approach: A) Developing a scientific literacy instrument based on a framework developed by conceptualising scientific literacy through the definition of scientific literacy from expert commentators or field observation, or a combination of both. Included in this group are mostly frameworks that were created before 2018; B)Developing a scientific literacy instrument by adopting a framework from studies in approach A; C)Developing a scientific literacy instrument by using the framework arising in approach A, but with slight modifications, such as combining or reducing the framework's components, while still keeping some part of the construct intact; D)Developing a scientific literacy instrument without using any framework. **Framework is not part of finding in the search result for this study's systematic review

As shown in Table 3, There is a combination of academic documents such as Gormally et al. (2012)and governmental documents, such as P-CAP 2013 and international project such as PISAmaking up the list. All of the governmental and project documents were not part of our final list. Meanwhile, all of the academic documents, except for SOLO Taxonomy, could be found in our list.This might be due to SOLO Taxonomy was a learning outcome taxonomy to assess the level of students' understanding rather than a scientficiliteracfy framework (J. Biggs, n.d.; J. B. Biggs & Collis, 1982). Hence, this article does not fot our critreria for the final list.

Table 4

New Scientific Literacy Framework Based on Frameworks in Table 3

No	Frameworks	Framework development approach*	Adaptation from framework	Distinctive features
1	Assessment of Civic Scientific Literacy (ACSEL)	C	PISA 2006	Assess Decision-making skill, assessment for adult
2	Student test of Scientific Literacy Integrated Character (SToSLiC)	C	PISA 2015	Assess students' national characters
3	Science for All America (SFAA)	C	Millar	Using different terms and jargons to address the original construct

Note. *Framework Development Approaches are divided into 4 approach: A) Developing a scientific literacy instrument based on a framework developed by conceptualising scientific literacy through the definition of scientific literacy from expert commentators or field observation, or a combination of both. Included in this group are mostly frameworks that were created before 2018; B)Developing a scientific literacy instrument by adopting a framework from studies in approach A; C)Developing a scientific literacy instrument by using the framework arising in approach A, but with slight modifications, such as combining or reducing the framework's components, while still keeping some part of the construct intact; D)Developing a scientific literacy instrument without using any framework

Additionally, there was one article that created its own scientific literacy framework (Benjamin et al., 2017) to assess the scientific literacy of prospective college and undergraduate students. The author also create scientific literacy instrument form the framework in the same article. However, this framework has not yet been adapted by other researchers.

The following section discusses the frameworks that we have identified and how they have been used to create a scientific literacy instrument. This review is followed by a discussion about our findings regarding the imperative role of context in translating the theoretical framework of scientific literacy into an instrument as a practical product. This section is arranged based on the sequence as shown in tables 3 and 4.

1. *PISA 2015*

The PISA 2015 Scientific Literacy Framework is the framework that OECD used in 2015 PISA. It was created by making major changes to the previous PISA frameworks (PISA 2012, PISA 2009 and PISA 2006). Unlike PISA 2006 (discussed in point 3), academic articles for the development process of the PISA 2015 scientific literacy framework were not published.In general, thisPISA framework has four interrelated aspects: context, content, competence and attitude. It is on the 2015 PISA framework that major changes were made from previous scientific literacy assessments. These changes could be seen in Table 5 at the "Notes" section, where changes of PISA framework were listed.

This study found that there was a total of 10 article reports about creating an instrument based on the PISA frameworks. Eight articles adapted the framework, and two articles do not provide sufficient information on how the frameworks were used -the author only mentioned (or through a citation) that the instrument was based on PISA 2015 Scientific Literacy Framework without giving sufficient elaboration on the framework or the instrument itself, as seen in Mawaddah et al., (2021) and Retno et al., (2018). It is worth noting that both articles shared a similar aim, which was focused on checking the effectiveness of a certain developed educational product, namely a learning model and learning module, to improve learners' scientific literacy.

There were various ways in which PISA frameworks were adapted. For example, Astriawati and Djuki (2019) and Gunawan(2021) only used the competence aspect of the four PISA 2015 scientific literacy aspects. The competence aspect consisted of three categories: explaining phenomena scientifically, evaluating and designing scientific enquiry, and interpreting data and evidence scientifically. On the other hand, Suhandi and Samsudin (2019) used the competence and knowledge aspects. The knowledge aspect consists of content knowledge, procedural knowledge, and epistemic knowledge.

Hastuti, Setianingsih, and Anjarsari (2020) used all four aspects of the PISA 2015 scientific literacy framework, namely context, knowledge, competence and attitude. However, they did not use the same construct with regard to the competence aspect. Instead of the three aspects of scientific literacy competence as listed in PISA 2015, they listed the competence as: explaining scientific phenomena, evaluating data and scientific evidence,and explaining the relationship between concept and application. Another article which shared the same construct for measuring scientific literacy is Widowatiet. al. (2018), however, their article was not included in the 10 articles that used PISA 2015 as instrument framework because they did not elaborate on the framework that they used to create the instrument.

Another approach to the adaptation of PISA 2015 scientific literacy framework could be seen in the instrument created by Susandi et al. (2020)which two out of four aspect of PISA 2015 scientific literacy framework, namely the knowledge aspect (only the content knowledge and procedural knowledge) and attitude aspect. This is slightly different from PISA 2015, because the knowledge aspect originally consisted of three aspects with the epistemic knowledge being the third knowledge assessed. All of the articles mentions above tend to left out some parts of PISA 2015 Scientfic Literacy Framework for reasons that was not much elaborated in the article.

Further, each instrument has a different format in translating the framework to the instrument. It ranges from multiplechoice questions to essay question items. For example, Sinaga et al. (2017), who measuredonly the competence and knowledge aspects, used the multiplechoice format with 35 question items. Jufri et al. (2019), who measured only the competence aspect, used multiple choice (42 question items) and the Likertscale (40 statements) format. Astriawati and Djuki (2019) and Nasution et al.'s (2019) instruments were developed in the form of essay questions and assessed using a marking key. These formats, although similar to the PISA 2015 scientific literacy format, were at the same time notably different. The PISA 2015 scientific literacy instrument format used constructed response, multiplechoice, and complex multiplechoice (such as choosing more than one response from a list and completing a sentence that has multiple blanks using drag and drop menu). Meanwhile, for attitude, a contextual questionnaire was used (OECD, 2017).

Research using the PISA 2015 scientific literacy framework for instruments were conducted in various contexts. Although PISA was originally created for use on 15-year-old pupils, in the abovestudies the researcher used it for different age ranges with different education levels.Suryanti(2021) created the instrument for primary school, Hastuti et al. (2020) for junior high school and Nasution et al. (2019) for senior high school. Among these education levels, only junior high school students resemble most with PISA 2015 respondents. The topic used also varied. Some of the topics used were specific, such as in Retno et al. (2018), who used thermochemistry as the main topic, and Susandi et al. (2020) who used direct durrent. Both research projects were conducted in senior high schools. Meanwhile, Hastuti et al. (2020) research were conducted in "integrated science" subjectin junior high school, similar to Suryanti (2021), who used healthy foodtopic in primary school. Both research contexts involve a more general and interrelated aspect of science.

2. *Test of Scientific Literacy Skills (TSOLS) Framework (Gormally, Brickman, and Lutz 2012)*

The Test of Scientific Literacy Skills or TSOLS is the second most referenced framework to create scientific literacy instrument. The TOSLS framework consisted of nine categories of scientific literacy:

1) Identify a valid scientific argument
2) Evaluate the validity of sources
3) Evaluate the use and misuse of scientific information
4) Understand elements of research design and how they impact scientific findings/conclusions

5) Create graphical representations of data
6) Read and interpret graphical representations of data
7) Solve problems using quantitative skills, including probability and statistics
8) Understand and interpret basic statistic
9) Justify inferences, predictions, and conclusions based on quantitative data (Gormally, Brickman, and Lutz 2012, page 367)

The first four categories are included in the first major category: understanding methods of inquiry that lead to scientific knowledge, while the last five categories are included in the second major category: organise, analyse, and interpret quantitative data and scientific information. Along with developing the framework, Gormally et al. (2012) also developed the instrument, which consisted of 28 question items in the form of multiplechoice questions.

Two articles used this framework for creating instrument assessments. In Ahmada(2021), the framework was used to create a new set of question items consisting of 20 multiplechoice items. New sets of question items created by D'Agostino(2020) consisted of 10 multiple choice items.

Two articles that adapted TOSLS did not specify which categories were adapted because the authors reconstructed the framework. For example, Nafiah(2020) created a distinctive framework based on TOSLS. A similar finding could also be found in Sastradika and Jumadi(2018), who adapted PISA 2015 Scientific Literacy, TOSLS, and SLA frameworks. Sastradika and Jumadi (2018) created their framework and each frameworks' scientific literacy aspects or categories does not immediately recognisable if it is not because they refer it in the citation in the method section (p.2).Still, conceptual correlation between the referenced framework with the new framework exist nonetheless.

Regarding the format of the instrument, Nafiah (2020) used an essay format (5 questions), while Sastradika and Jumadi (2018) usedthe multiplechoice format (20 questions). Both studies were conducted in Indonesia within different contexts. Nafiah (2020) conducted her study with undergraduate students who were taking a national resource management course,whileSastradikadanJumadi(2018) conducted her study with senior high school students who were taking physics.

3. *Scientific Literacy Assessment (SLA)*

Scientific Literacy Assessment or SLA is a framework of scientific literacy instrument created by Fives. This framework consisted of 5 constructs: role of science, scientific thinking and doing, science and society, mathematics in science, and science motivation and beliefs (Fives et al., 2014). Based on this framework, the author created two sets of measures to be administered into one scientific literacy instrument. The first set is the SLA-D to assess demonstrated scientific literacy. This set has 26 multiple choice items. The second set is SLA-MB to assess motivation and beliefs associated with scientific literacy. This set has 25 Likert items.

There was only one instrument created based on the SLA framework, being the one by Satsradika and Jumadi, who also referenced the PISA 2015 scientific literacy framework and TOSLS framework. However, unlike the other two frameworks, SastradikadanJumadi (2018) used SLA as the basis of their scientific literacy instrument and then used the other two frameworks (PISA and TOSLS) to modify the SLA framework according to his needs. Satsradika and Jumadi's (2018) research aim was to develop a subject-specific pedagogy, and the scientific literacy instrument in this article was created to measure the effectivieness of the pedagogy to improve scientific literacy.

4. *PISA 2006 and PISA 2012*

PISA 2006 scientific literacy framework was developed in 21 months starting in 2002 and concluded in August 2004. The development of the framework involved at least two major institutions: OECD and The Australian Council for Educational Research (ACER) Consortium. OECD developed the initial framework, and then continued ACER consortium continued the development resulting in the PISA 2006 Scientific literacy framework (Bybee et al., 2009; OECD, 2009a).

PISA 2012 Scientific Literacy Framework was modified from the original framework, which was first developed by Bybee, McCrae, and Laurie and was used in PISA 2006, of which the developed framework were also reported in 2009 (Bybee et al., 2009). Bybee et al. (2009) reported the development of the PISA scientific literacy framework in an academic journal three years after the PISA 2006 program was conducted.

Like PISA 2015, both PISA 2006 and 2012 scientific literacy frameworks have four interrelated aspects: context, content, competence, and attitude. However, the construct for each aspect is different from PISA 2015, as shown in Table 5. The difference between PISA 2006 and 2016 is that in PISA 2012 scientific literacy assessment, the attitude aspect was not assessed.

In this study, we found one article that had adapted PISA 2006 and one that had adapted PISA 2012. None of these articles cited Bybee et al. (2006) as the basis of instrument creation. Instead, they cited PISA report documents. The article which used PISA 2012 framework is Rubini(2017). He developed an instrument to measure junior high school science teachers' scientific literacy. However, he did not further elaborate on which aspects were used. In his Discussion section, he only reported teachers' knowledge about science based on the construct of knowledge aspect of PISA 2012 scientific literacy framework. Meanwhile, another article which used PISA 2006 scientific literacy framework will be discussed in point 10.

Table 5

PISA Scientific Literacy Framework from 2006 to 2018

No	PISA 2006 and 2009 (Bybee et al., 2009; OECD, 2013)	PISA 2012 (OECD, 2013)	PISA 2015 (OECD, 2017)	PISA 2018 (OECD, 2019)
1		Context		
1.a.	Life situation	Life situation	Personal	Personal
1.b.	Science and Technology	Science and Technology	Local/national	Local/national
1.c.	-	-	Global	Global
2		Knowledge		
2.a.	Knowledge about the natural world	Knowledge about the natural world	Content Knowledge	Content Knowledge
	1. Physical system	*1. Physical system*	*1. Physical system*	*1. Physical system*
	2. Living system	*2. Living system*	*2. Living system*	*2. Living system*
	3. Earth and space system	*3. Earth and space system*	*3. Earth and space system*	*3. Earth and space system*
	4. Technology system	*4. Technology system*	-	-
2.b.	Knowledge about science	Knowledge about science	Procedural knowledge	Procedural knowledge
	1. Scientific enquiry	*1. Scientific enquiry*	*(excluded in this table)*	*(excluded in this table)*
	2. Scientific explanation	*2. Scientific explanation*		
2.c	-	-	Epistemic Knowledge	Epistemic Knowledge
	-	-	*1. The constructs and defining features of science.*	*1. The constructs and defining features of science.*
	-	-	*2. the role of 1 in justifying the knowledge produced by science*	*2. the role of 1 in justifying the knowledge produced by science*
3.		Competence		
3.a.	Identifying Scientific Issues	Identifying Scientific Issues	Explain phenomena scientifically	Explain phenomena scientifically
	1. Recognising questions that it would be possible to investigate scientifically in a given situation	*Recognising issues that are possible to investigate scientifically*	*1. Recall and apply appropriate scientific knowledge*	*1. Recall and apply appropriate scientific knowledge*
	2. identifying keywords to search for scientific information on a given topic	*Identifying keywords to search for scientific information*	*2. Identify, use and generate explanatory models and representations.*	*2. Identify, use and generate explanatory models and representations.*

No	PISA 2006 and 2009 (Bybee et al., 2009; OECD, 2013)	PISA 2012 (OECD, 2013)	PISA 2015 (OECD, 2017)	PISA 2018 (OECD, 2019)
	3. Recognising key features of a scientific investigation	*Recognising the key features of a scientific investigation*	*3. Make and justify appropriate predictions.*	*3. Make and justify appropriate predictions.*
	-	-	*4. Offer explanatory hypotheses.*	*4. Offer explanatory hypotheses.*
	-	-	*5. Explain the potential implications of scientific knowledge for society.*	*5. Explain the potential implications of scientific knowledge for society.*
3.b.	Explaining scientific phenomena	Explaining phenomena scientifically	Evaluate and design scientific enquiry	Evaluate and design scientific enquiry
	1. describing or interpreting phenomena and predicting changes	*1. Applying knowledge of science in a given situation*	*1. Identify the question explored in a given scientific study.*	*1. Identify the question explored in a given scientific study.*
	2. recognising or identifying appropriate descriptions, explanations, and predictions	*2. Describing or interpreting phenomena scientifically and predicting changes*	*2. Distinguish questions that could be investigated scientifically.*	*2. Distinguish questions that could be investigated scientifically.*
			3. Propose a way of exploring a given question scientifically.	*3. Propose a way of exploring a given question scientifically.*
	-	*3. Identifying appropriate descriptions, explanations, and predictions*	*4. Evaluate ways of exploring a given question scientifically.*	*4. Evaluate ways of exploring a given question scientifically.*
	-	-	*5. Describe and evaluate how scientists ensure the reliability of data, and the objectivity and generalizability of explanations*	*5. Describe and evaluate how scientists ensure the reliability of data, and the objectivity and generalizability of explanations*
3.c.	Using scientific evidence	Using scientific evidence	Interpret data and evidence scientifically	Interpret data and evidence scientifically
	1. selecting from alternative conclusions in relation to evidence;	*Interpreting scientific evidence and making and communicating conclusions*	*1. Transform data from one representation to another.*	*1. Transform data from one representation to another.*
	2. giving reasons for or against a given conclusion in terms of the	*Identifying the assumptions, evidence and reasoning behind*	*2. Analyse and interpret data and draw appropriate conclusions.*	*2. Analyse and interpret data and draw appropriate conclusions.*

No	PISA 2006 and 2009 (Bybee et al., 2009; OECD, 2013)	PISA 2012 (OECD, 2013)	PISA 2015 (OECD, 2017)	PISA 2018 (OECD, 2019)
	process by which the conclusion was derived from the data provided;	*conclusions*		
	3. identifying the assumptions made in reaching a conclusion	*Reflecting on the societal implications of science and technological developments*	*3. Identify the assumptions, evidence and reasoning in science-related texts.*	*3. Identify the assumptions, evidence and reasoning in science-related texts.*
			4. Distinguish between arguments that are based on scientific evidence and theory and those based on other considerations.	*4. Distinguish between arguments that are based on scientific evidence and theory and those based on other considerations.*
			5. Evaluate scientific arguments and evidence from different sources (e.g. newspapers, the Internet, journals).	*5. Evaluate scientific arguments and evidence from different sources (e.g. newspapers, the Internet, journals).*
4.	Attitude (was not administered in 2009 and 2012)		Attitude	Cognitive demand (constructing the test items outside SL aspects)
4.a	Interest in science,	Interest in science,	Interest in science	Low
4.b.	Support for scientific inquiry	Support for scientific inquiry	Valuing scientific approaches to inquiry	Middle
4.c.	Motivation to act responsibly	Motivation to act responsibly	Environmental awareness	High
O	Notes			
	Aspect that is consistent with the main conception of SL for assessment purpose (p. 130) is only the competencies aspect. Other aspect is still use different wordings/terms to refer to a certain assessment aspect. Eg. For context, life situation is	The competence is stated in a more standardized manner (a table to list the competencies was provided).	Several visible changes toward scientific literacy aspects' components (OECD, 2017), such as for context, knowledge (omission of technology for content, and addition of two forms of knowledge), competence, and attitude (additional focus on	No more referenced on Bybee's work (relating to 2006, 2009, and 2012 scientific literacy framework) No significant difference in SL aspects and its construct, except omission of attitude aspect in the main conception

No	PISA 2006 and 2009 (Bybee et al., 2009; OECD, 2013)	PISA 2012 (OECD, 2013)	PISA 2015 (OECD, 2017)	PISA 2018 (OECD, 2019)
	referred as “personal, social and global” (OECD, 2017) Context aspect are fleshed out in a manner which is not word to word similar to what is written in p.130 The competence is not yet bulleted as in the next following years		environmental awareness and active attitude towards scientific approach). All aspects is stated in a more standardized manner (using the same term consistently throughout the document as seen in OECD (2017). Procedural knowledge derivatives are omitted from this table because the document only listed “examples” of what was measured. Unlike epistemic knowledge which mentioned 2 points of “major features”	of SL for assessment purposes (p. 102). Additional key feature across three aspects is added in form of cognitive demand.

5. *Pan-Canadian Assessment Program 2013 (P-CAP 2013)*

The Pan Canadian Assessment Program 2013 is a programmeinitiated in 2013 by the CanadianCouncil Ministers of Education to assess how well the education system meets the need of society (O'Grady & Houme, 2015). The science domain of P-CAP 2013 is divided into three competencies (science inquiry, problemsolving, and scientific reasoning); four sub-domains (nature of science, life science, physical science, and Earth science); and attitudes, within a given context. When translated into an instrument, the format of the P-CAP 2013 question items is includes selected response items (multiplechoice, true or false, etc.) and constructedresponse items (short phrases to several paragraphs).

Shofiyah(2020) developed an instrument based on the P-CAP framework made up of essay-type questions. The instrument was administered before and after an intervention involving a teaching approach as the aim of the test was to evaluate the effects on the scientific literacy of Indonesian junior high school pupils.

6. *Miller (1983)*

Miller conducted a conceptual and empirical review of research related toscientific literacy in 1983. He provided a framework to discuss about scientific literacy in the United States. His conception of scientific literacy was as follows: 1) The norms and Methods of Science, 2) Cognitive Science Knowledge, and 3) Attitudes toward Organized Science (Miller, 1983).Later, this framework was adapted to create scientific literacy instrument for the development of question items for Science for All Americans (SFAA) project in Phase II (Laugksch & Spargo, 1996),which will be discussed in point 12.

7. *Taiwan Ministry of Education*

TheTaiwan Ministry of Education (MoE) released their version of scientific literacy in 1998. The constructs were defined into six themes: scientific cognition, process skills, nature of science, attitude towards science, habits of mind, and application of science. Taiwan MoE translated this framework into multiple choice questions in the science section of Taiwan's Academic Attainment Testing, known as STAAT, which was used as the national entrance examination to enter senior high school (Chang & Chiu, 2005).

In the article that we found, Chang and Chiu (2005) developed a different assessment that used authentic assessment, assessment developed around the idea of measuring students competence that is applicable in the real world context, to measure the scientific literacy of the 9thgrade junior high school pupils. The authors identified the authentic features of each theme and determined what kind of test format was suitable to assess those themes. The new instrument that was created used not only multiplechoice format, but also open-ended questions, hands-on activities, and Likert scale items. Chang and Chiu's aim was to discuss the different formatsfor authentic assessment.

8. *Standard Observed Learning Outcomes (SOLO) Taxonomy*

The Standard Observed Learning Outcomes (SOLO) taxonomy was developed by Biggs and Collins (1982). This taxonomy comprises of five levels of understanding: pre-structural, unistructural,multi-structural, relational, andextended abstract. At the pre-structural level, the pupils may not understand the matter or miss the point. At theunistructural, pupils are able to identify, name, or follow simple procedure. At the multi-structural level they may understand several independent aspects but not able to make connections between those aspects. At the relational level, pupils can make connections between aspects within the same domain and can execute more complex tasks such as applying, analysing or justifying. At the extended abstract level, learners can generalise relationships between aspects from level 4 to a different domain. They are also able to execute complex metacognitive tasks such as creating, reflecting and theorising(Anderson & Krathwohl, 2001; J. Biggs, n.d.; J. B. Biggs & Collis, 1982)

Vogelzang et al. (2020) created an instrument to assess grade 11 pupils' critical scientific literacy in the topic of Green Chemistry based on the SOLO Taxonomy involving twelve open questions abouttwelve principles of Green Chemistry. They were then asked to apply the twelve principles to two different synthesis routes to adipic acid. The third task was to write a balanced report on which of both routes is the greener one. Participants' critical scientific literacy was assessed by reviewing their written reportsusing 5 levels of SOLO taxonomy.

9. *Scientific Literacy Survey for College Preparedness in STEM (SLSCP-STM)*

The Scientific Literacy Survey for College Preparedness in STEM or SLSCP-STM was developed specifically to measure the preparedness of students who are about to enter 4-year colleges or universities for STEM majors. Benjamin et al. developed the instrument by first developing a framework based on integrating three definitions of scientific literacy: utilitarian scientific literacy, Miller's civic scientific literacy (1998), and the 1996 National Research Council's definition.

There were three domains within the SLSCP-STM: attitudinal and behavioural, content knowledge, and scientific reasoning. Each domain was broken down into a more detailed construct as reported in Benjamin et al. (2017). In the instrument created based on the framework, Likert-scale items were created to measure attitude, True-False items to measure content knowledge, and a multiplechoice question with 6 options to measure scientific reasoning.

10. *Assessment of Civic Scientific Literacy (ACSEL)*

Naganuma(2017) created a scientific literacy instrument used to measure civic scientific literacy of Japanese citizens above 20 years old. The instrument is called Assessment of Civic Scientific Literacy or ACSEL. This instrument was created due to his concern of PISA scientific literacy assessment did not include assessment for decision making, which he was supposed to be due to PISA 2006 test only assess 15 years old students' competency. Meanwhile, he argued that decision making skill is an important aspect of scientific literacy. Hence, he developed an instrument which include decision-making skill based on objective information.

ACSEL used two out of four PISA aspects namely the competency and context aspects. The competency aspect of ACSEL is subdividedinto using scientific evidence, explaining scientific inquiry, and making decisions based on objective information (Naganuma, 2017). The first two constructs were from the PISA 2006 competency construct, while the third was created from his own research. ACSEL also used the context aspect of PISA by using three of its contexts: the frontiers of science and technology, health, and environmental quality. The framework was translated into an instrument made up of 10 constructresponse question items. Two of them were taken from the PISA 2006 Scientific literacy questions, while eight other questions were newly developed.

11. Student Test of Scientific Literacy Integrated Character (SToSLiC)

Jufri, Hakim and Ramdani(2019) created theStudent Test of Scientific Literacy Integrated Character (SToSLiC) with aim to make a scientific literacy instrument that also integrated with students' characters. The instrument is considered to be necessary for Indonesian teachers because improving scientific literacy and strengthening pupils' character educationhas been one of the aims of the Indonesian education system. Character education in Indonesia's context is education which aims to

This Instrument was created by adopting the competency aspect of PISA 2015 Scientific Literacy framework (OECD, 2017) and 6 out of 18 National Characters (*Peraturan Presiden Republik Indonesia Nomor 87 Tahun 2017 Tentang Penguatan Pendidikan Karakter*, 2017). Similar to SLA-, SToSLiC was divided into two parts:SToSLiC-A, consisting of 42 multiple choice questions to assess scientific literacy, and SToSLiC-B, consisting of 42 Likert-scale items to assess students' character.

12. Science for All America (SFAA)

Laugksch and Spargo's(1996) article was prompted by Phase II of Project 2061, a long-term project of the American Association for the Advancement of Science (AAAS). Laugksch and Spargo aimed to reformulate the goals of for scientific literacy in Science for All America (SFAA) report from Phase I and develop an item bank to create instruments to assess American school learners' scientific literacy. The reformulation process uses Miller's three dimension of scientific literacy. In this article however, the terms used were slightly different. The three dimensions of Miller's scientific literacy in this article were written as: 1) the nature of science, 2) cognitive science knowledge, and 3) science and technology's impact on society.

Articles with Insufficient Information about the Scientific Literacy Instrument

Included in this section are 16 articles. Most of these articles' main aim was not to create a scientific literacy framework, but they state (explicitly or implicitly) that a scientific literacy instrument was developed. Most of these instruments were created as a way to assess whether a certain product(such as books, appslication or other learning source) has been successful in improving scientific literacy (Hardianti& Wusqo, 2020; Hartini, 2018).

Some articles describe the instrument's construct without making explicit or direct references between the construct with any known framework or theories in the explanation of instrument development, e.g., Jalil et al., 2019; Rusilowati et al., 2018). However, having examined the frameworks above and using Google search, the authors managed to identify some of these frameworks. These articles would be included in Group B if not for the insufficient information provided in the article regarding which framework that were adopted for the development process. The following list shows some frameworks that those authors might use based on the construct's similarity to known frameworks.

Table 5

Possible Frameworks Adapted in Instrument with Insufficient Information

No	Frameworks
1	PISA 2015
2	Test of Scientific Literacy Skills (TSOLS) (Gormally et al., 2012)
3	Categories of Scientific Literacy in High School Books (Chiappetta, Sethna and Fillman, 1991)
4	Bloom Cognitive Taxonomy

Besides PISA 2015 and TOSLS, two new frameworks were used as the possible basis for creating a scientific literacy instrument. Chiapetta in 1991 developed a framework used to analyse high school science books. The framework was a set of themes of scientific literacy which consisted of four aspects: knowledge of science, the investigative nature of science, science as a way of thinking, andthe interaction of science, technology, and society (STS) (Chiappetta, et al 1991, page 942). An article that subsequently used this framework to create a scientific literacy instrument was Rusilowati et al. (2018). It consisted of 20 multiplechoice items on the topicof energy.

Bloom's Cognitive Taxonomy is widely used to assess cognitive learning outcomes. It consists of six cognitive levels: remembering, understanding, applying, alysing, evaluating, and creating (Anderson & Krathwohl, 2001). An article that used this framework to create a scientific literacy instrument is Hartini(2018). The instrument consisted of 9 questions ranging from C2 to C4 level in Bloom Taxonomy.

Scientific Literacy Instrument without Scientific Literacy Framework as Indicator

There is only one article which conforms to the title of this subsection. This article reported the creation of an instrument to measure scientific literacy without using a scientific literacy framework as the basis of the instrument's creation. The instrument created in this manner is reported by Tomas, who developed a scale to measure 9th graders' scientific literacy in Australia. It was applied to a study to evaluate pupils' scientific literacy based on their written stories about socio-scientific issues ofbiosecurity. For the creation of the rubric, there were no particular framework created. In this study the rubric was developed qualitatively based on the task and the answer of students to the task. There were two constructed response items. Students were asked to demonstrate their conceptual understanding in a written story about the socio-scientific issue of biosecurity subject in a clear language.

Pupils' conceptual understanding was categorised into three levels:

> *Firstly, some stories did not include any of the required information specified in the task. Secondly, the majority of the stories attempted to include most of the information required, with some inaccuracies or alternative conceptions evident. Thirdly, some stories met the task requirements fully, completely and accurately.*(Tomas & Ritchie 2015, p. 46)

Development of Scientific Literacy Instrument Thus Far

The current development of scientific literacy instrumentshas beenmostly based on scientific literacy frameworks (42 out of 43 articles). Most adopted or adapted the PISA 2015 Scientific literacy framework. The use of this framework wasmostly reported in 2017-2021. Besides that, most instruments created based on existing frameworks (Group B and C) were mostly reported during the same year span. Articles that reported on the development of an instrument started by independent construction of a framework based on theoretical conceptions of scientific literacy (Group A, 6 articles) can no longer be found during this period.

The creation of a scientific literacy assessment tool using Approach A is understandably more laborious since it requires more steps to create the instrument. Not only are the researchers supposed to create an instrument based on any existing framework as reference, the authors also have to construct the framework on their own(Benjamin et al., 2017; Bybee et al., 2009; Fives et al., 2014; Gormally et al., 2012). Based on practicality, approaches B and C are preferable especially when the research aims not to create the instrument itself but for other aims such as creating a tool to assess the effectiveness of a certain intervention in improving scientific literacy (Hufri, 2019; Sastradika & Jumadi, 2018).

With regard to a framework, PISA 2015 seems favourable considering that it has four aspects that could represent different dimensions for creating a scientific literacy instrument. However, no instrument created based on PISA 2015 used the complete framework or adopted it fully by using all four aspects and their derivatives. This is unlike the TOSLS framework created by Gormally et al. which has been adopted by researchers to create another instrument(Ahmada et al., 2021; D'Agostino, 2020). Gormally et al's. framework has a total of nine categories (page 10), each of the categories being an indicatorof the scientific literacy of the respondent (Gormally et al., 2012). This is unlike in PISA where the four aspects were broken down into more specific component. For example, the knowledge aspect in PISA is constructed of content, procedure, and epistemic knowledge (Bybee et al., 2009; OECD, 2017).

However, the lack of articles that devise a scientific literacy approach in the last three years suggests that future researchers should consider participating in such studies. This is considering how useful any framework created in this approach for other researchers in developing a scientific literacy approach, as demonstrated by the number of articles that used approaches B and C to create their instrument

This study also found that although a framework was adopted fully, researchers could make changes to the format of the instrument, such as found in Chang and Chiu (2005) article (2005). They used the same framework from Taiwan MoE but proposed a different format. The consideration was whether the current instrument in the MoE has optimally assessed students' scientific literacy. They found that using their format was more optimal when the two were compared. This form of changeis considered an improvement to the original instrument. However there were also changes of formats that were not disclosed (Astriawati & Djukri, 2019; Jufri et al., 2019; Susandi et al., 2020). For example, in Jufri et al. (2019) and Astriawati and Djukri (2019), the format chosen was not as diverse as in PISA 2015 question format. Jufri et al (2019) used only multiple-choice questions and Likert-scale items, while Astriawati and Djukri (2019) used essay questions with an assessment key. However, the reason for this decision was not elaborated on.

However, this study also found an interesting work by Tomas and Ritchie (2015) that develops scientific literacy instrument not based on a scientific literacy framework, but directly based on definition of the two goals of scientific literacy by Roberts (2007). Their work was quite interesting because after they accepted the Roberts two visions about scientific literacy, they decided to give their students tasks that correspond to those views and how scientific literacy would look in action. They tried to use SLA as the basis of scientific literacy assessment in their context. However, when the framework was used, it was considered as not quite nuanced to capture their students' skill, they decided to create a rubric based on the task instead. No framework was created for this instrument (Tomas & Ritchie, 2015).

Although scientific literacy assessments have been created mainly through developing and referring to a scientific literacy framework, developing it using a different approach is not impossible for future developers of scientific literacy instruments. However, considering the task that was given in Tomas and Ritchie (2015) is in the form of a constructed-response format (Tomas & Ritchie, 2015), it is advisable to consider the practicality of such instrument when created for large scale research (Turner, 2017).

Conclusion

Using a scientific literacy framework is a popular approach to devising a scientific literacy instrument. Researchers have been found to independently construct, adopt or adapt a scientific literacy framework, or reconstruct an existing framework to create a new framework in their attempt to create a scientific literacy instrument. The trend over the past three years show that a scientific literacy framework has been useful in aiding researchers to conduct research where scientific literacy improvement or scientific literacy measurement was the main objective. More scientific literacy frameworkis needed to help future researchers in their attempt to create scientific literacy that fits the contextual research needs.

However, this study also found a rare attempt to approach scientific literacy assessment differently than explained above. Future studies on the development of scientific literacy instruments should also consider this option as an alternative while also considering the practicality of the developed instrument depending on its context.

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Appendix 1

List of Article Reviewed

Year	Title	Authors	Approach	Framework
1996	Development of a pool of scientific literacy test-items based on selected AAAS literacy goals	Laugksch & Spargo	A	Miller, 1983
2005	The development of authentic assessments to investigate ninth graders' scientific literacy: In the case of scientific cognition concerning the concepts of chemistry and physics	Chang & Chiu	C	Taiwan MoE
2009	PISA 2006: An assessment of scientific literacy	Bybee, McCrae, and Laurie	A	PISA 2006
2012	Developing a test of scientific literacy skills (TOSLS): Measuring undergraduates' evaluation of scientific information and arguments	Gormally, Brickman, and Lutz	A	TOSLS
2014	Developing a measure of SL for middle school students	Fives, Huebner, Birnbaum	A	SLA
2015	The Challenge of Evaluating Students' Scientific Literacy in a Writing-to-Learn Context	Tomas and Ritchie	No framework	-
2017	Development and Validation of Scientific Literacy Scale for College Preparedness in STEM with Freshmen from Diverse Institutions	Benjamin, Marks, Demtrikopoulos	A	SLSCP-STM
2017	Using scientific-inquiry activities for developing teachers' and supervisors' scientific literacy	Ladachart, Yuenyong	unavailable in english	unavailable in english
2017	An assessment of civic scientific literacy in Japan: development of a more authentic assessment task and scoring rubric	Naganuma	B	ACSEL
2017	Professional development model for science teachers based on scientific literacy	Rubini, Ardianto, & Pursitasari	C	PISA 2012
2017	Improving secondary school students' scientific literacy ability through the design of better science textbooks	Sinaga, Kaniawati, and Setiawan	B	PISA 2015
2017	The effectiveness of multi modal representation text books to improve student's scientific literacy of senior high school students	Zakiya, Sinaga, Hamidah	insufficient	PISA, TOSLS
2018	Reinforcement of scientific literacy through effective argumentation on an energy-related environmental issue	Chen and Liu	insufficient	insufficient information

Year	Title	Authors	Approach	Framework
2018	How to develop students' scientific literacy through integration of local wisdom in Yogyakarta on science learning?	Hastuti, Setianingsih, Anjarsari	B	PISA 2015
2018	Development of assessments for scientific literacy based on curriculum guidelines for 12-year basic education in science domains	Lin, Pan, Su, Chen	unavailable in english	unavailable in english
2018	Properness test: Development of an inquiry-based learning module to improve science literacy in thermochemistry subject	Retno, Saputro, Ulfa	B	PISA 2015
2018	The development of scientific literacy assessment to measure student's scientific literacy skills in energy theme	Rusilowati, Nugroho, Susilowati, Mustika, Harfiyani, Prabowo	B	Chiappetta
2018	Development of subject-specific pedagogy based on guided inquiry about newton's law to improve senior high school students' scientific literacy ability	Sastradika, Jumadi	B	PISA 2015, SLA, TOSLS
2018	Applying innovative approach "nature of Science (NoS) within inquiry" for developing scientific literacy in the student worksheet	Widowati, Anjarsari, Zuhdan, Dita	insufficient	PISA
2019	Developing Chamilo-Based E-Learning in Environmental Change Material to Enhance Students' Scientific Literacy Skills	Astriawati, Djukri	B	PISA 2015
2019	Effects of green chemistry based interactive multimedia on the students' learning outcomes and scientific literacy	Hadisaputra, Gunawan, Yustiqvar	article unavailable	article unavailable
2019	Developing of physics teaching material based on scientific literacy	Hartini, Latifah, Salam, and Misbah	insufficient	Bloom
2019	Practicality and effectiveness of physics teaching materials based on contextual through inquiry to increase studentsscience literacy	Hufri, Sari, Deswita, Wahyuni	insufficient	unclear
2019	Development of A-SSI Learning Media (Android Social Scientific Issues) to Improve Science Literation in Earth Coating Subject for First Grade of Junior High School	Jalil, Prastowo, Widodo	insufficient	unclear
2019	Instrument Development in Measuring the Scientific Literacy Integrated Character Level of Junior High School Students	Jufri, Hakim, and Ramdani	C	PISA 2015; Indonesia students' character

Year	Title	Authors	Approach	Framework
2019	Development of digital learning media based on android games with joyful inquiry model to increase science literacy skills for second year students of junior high school in subject matter of vibration	Marsuki, Suwono, Slamet	insufficient	insufficient
2019	Correlation reading infusion (RI) and scientific literacy competence (SLC) XI grade students on sound wave topic	Maulidia, Utari, Karim, Saepuzaman, Nugraha, Prima	insufficient	insufficient
2019	Development of scientific literacy instruments based on PISA framework for high school students on global warming topic	Nasution, Liliawati, Hasanah	B	PISA 2015
2019	Effectiveness of the use of developed teacher's book in guiding the implementation of physics teaching that provides science literacy and instill spiritual attitudes	Suhandi, Samsudin.	B	PISA 2016
2020	Development of SL through STEM project in Biology classroom	Ahmada, Suwono, Fachrunnisa	B	TOSLS
2020	Developing an instrument for students scientific literacy	Atta, Vlorensius, Aras, Ikhsanudin	insufficient	unclear
2020	Teens learning epidemiology? A cohort study on epidemiology instruction for high school youth	D'Agostino	B	TOSLS
2020	Fostering students' scientific literacy and communication through the development of collaborative-guided inquiry handbook of green chemistry experiments	Hardianti, Wusqo	insufficient	unclear
2020	Mobile-nature of science model of learning for supporting student performance on general chemistry classroom	Khery, Masjudin, Muzaki, Nufida, Lesnawati, Rahayu, Setiawan	insufficient	unclear
2020	Elite (E-Book Literacy) for Junior High School Student's Scientific Literacy in Solar System Material	Kusumawati, Wasis, Sanjaya, Kholiq,	B	PISA 2015
2020	Development of Google Form Based on Scientific Literacy Principles for Junior High School Students in Heat Material	MM, Irwandani, Asniati, Anwar, Subandi	insufficient	unclear
2020	Preliminary research in the development of physics teaching materials that integrate new literacy and disaster literacy	Mufit, Asrizal, Hanum, and Fadhilah	insufficient	unclear

Year	Title	Authors	Approach	Framework
2020	The effectiveness of teaching instruments about management invasive alien species Acacia nilotica (L.) Willd. ex Del. through problem-based learning (PBL) models toward students scientific literacy and cognitive learning outcomes	Nafiah, Suhadi, Sari	B	TOSLS
2020	Development and Validation of students' Worksheet Based on Guided-Inquiry to Improve Students' Scientific Literacy Skills of Junior High School on Straight Motion Concept	Sari, Abdurrahman, Herlina	insufficient	unclear
2020	The analysis of ethnoscience-based science literacy and character development using guided inquiry model	Sarwi, Alim, Fathonah, Subali	insufficient	unclear
2020	Scientific Approach and the Effect on Students Scientific Literacy	Shofiyah, Afrilia, Wulandari	B	P-CAP 2013
2020	Development of science literacy instruments in the direct current	Susandi, Jannati, Rachmat, karniawati, Siahaan	B	PISA 2015
2020	Effects of Scrum methodology on students' critical scientific literacy: The case of Green Chemistry	Vogelzang, Admiraal, Driel	B	SOLO taxonomy
2021	Guided inquiry blended learning tools (GI-BL) for school magnetic matter in junior high school to improve students' scientific literacy	Gunawan, Jufri, Nisrina Al-Idrus, Ramdani, Harjono	B	PISA 2012
2021	RICOSRE: An innovative learning model to promote scientific literacy	Mawaddah, Mahanal Gofur, Setiawan, Zubaidah	B	PISA 2015, TOSLS
2021	Gadget-Based Interactive Multimedia on Socio-Scientific Issues to Improve Elementary Students’ Scientific Literacy	Suryanti,	B	PISA 2015