Assessing literacy practices and futures in science and mathematics classrooms: A systematic review

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Integrating literacy in science and mathematics learning and teaching has been an ongoing endeavour. There are frameworks developed to guide teachers' practices, but little is reported on assessing literacy simultaneously with scientific or mathematical content knowledge. We reviewed the literature on assessing literacy in science and mathematics to develop a coherent knowledge base using the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA). We accessed 683 peer-reviewed publications from three databases, and upon application of exclusion criteria, only 13 articles remained for full analysis. We report the macro skills focused, assessment tools and strategies used, and reported outcomes. We also discuss the geographical, practical, and theoretical gaps and highlight critical areas for future investigations.

Introduction

Across the globe, literacy is a significant focus in schools because reading, writing, listening, and speaking are essential macro-skills that enable individuals to participate fully in society. Literacy allows people to access information, communicate effectively, and make informed decisions (Mkandawire, 2018; Genc & Erbas, 2019). It is also a critical factor in economic development and can positively impact people's income and quality of life. Consequently, educational bureaucracies emphasise improving students' literacy for effective communication and learning (Mante-Estacio et al., 2018).

Research has reported that students with higher literacy skills tend to have better scientific and mathematical skills (Öztürk et al., 2020). Literacy and numeracy are closely related, and reading and understanding written instructions and information are essential for science and mathematics content knowledge learning. Students must be able to read and comprehend text, understand diagrams and graphs, and use written language to communicate their thoughts to solve complex science and mathematics problems (OECD, 2018). Therefore, students with strong literacy skills are better equipped to learn and succeed in science and mathematics.

The integration of literacy in science and mathematics teaching has been widely studied recently, with research demonstrating its effectiveness in improving student learning and achievement. A range of evidence shows that incorporating literacy strategies into science and mathematics instruction can improve students' understanding and retention of content knowledge (Cromley et al., 2010; Graham & Hebert, 2011; Ketonen et al., 2020; Graham, 2020). Similarly, several studies found that writing activities improve student learning in science, mathematics, and other key learning areas (Liang & Tsai, 2010; O'Mahony, 2021; Graham et al., 2020). In addition, questioning as a spoken activity in Mathematics classes helps to deepen students' understanding of mathematical concepts (Baiduri, 2017). Also, writing activities increase student achievement in science (Biyik & Şenel, 2019). Further, the integration of speaking activity helps students comprehend mathematical diagrams better as they can express their understanding through speaking (Wille, 2020; Nikolic et al., 2018). In other words, students must have strong literacy skills to truly understand scientific and mathematical concepts (Ojose, 2011; Windschitl et al., 2020). For example, suppose students struggle with reading comprehension. In that case, they may have difficulty understanding the instructions and concepts presented in the science or mathematics classroom, particularly in critical skills like comparing explanations, arguing evidence, critiquing a model, and unpacking claims (Windschitl et al., 2020). Their low literacy will result in poor assessment outcomes and difficulty meeting educational milestones (Wahyuni et al., 2018).

While integrating literacy into science and mathematics lessons is well-researched to be effective, assessing literacy while simultaneously assessing the content knowledge and using the assessment data to adapt learning and teaching activities remains relatively unexplored. To be truthful to the aim of integrating literacy in science and mathematics classes, teachers should know how to assess student literacy in the classroom to identify and address their literacy needs. A range of research evidence shows that by using assessment, teachers can determine students' areas for improvement in reading, writing, speaking, listening, and other specific language skills concerning science and mathematics content (Alt, 2018; Casey et al., 2018; Odegaard et al., 2015). Assessing literacy in these subjects can provide valuable insights into what individual students need literacy skills to be successful in their learning. By assessing students' literacy skills, teachers can identify areas where they may need additional support and tailor their teaching and materials to meet those needs better. In this way, assessing literacy in science and mathematics can help teachers support student learning and development. This study explores how assessing literacy in science and mathematics is researched and reported in the literature. It aims to develop a knowledge base to guide teaching practices and future research. In this literature review, we answer the following research questions:

1. How is assessing literacy in science and mathematics reported in the literature?
2. What approaches are used to assess literacy in science and mathematics?

Integration of literacy in science and mathematics

Literacy refers to the knowledge and skills associated with reading, writing, speaking, and listening, manifested in how students understand and utilise written and printed materials in various contexts and communicate through symbols, sounds, and images (Huettig & Pickering, 2019). Studies have consistently demonstrated that literacy is crucial for individual and societal success, enabling people to engage fully in economic, social, and cultural activities (Graff, 2023). For instance, research by the Organization for Economic Cooperation and Development (OECD) found that individuals with higher literacy levels tend to have better health outcomes, more employment opportunities, and greater levels of civic participation (OECD, 2016). This critical importance of literacy provided the stimulus for integrating it into all subject areas, such as science and mathematics.

The integration of literacy in science and mathematics education can have a positive impact on student learning and engagement in these subjects. Literacy strategies can support the understanding and retention of scientific and mathematical concepts (Herlanti et al., 2019).

Furthermore, when students can learn science concepts alongside literacy, they acquire essential discipline-specific vocabulary and language for future academic success (Gee, 2004; Nagy & Townsend, 2012; Tolbert et al., 2014). Integrating literacy in science and mathematics can also support the learning of students with disabilities, who may benefit from multiple modes of representation and scaffolding to access and comprehend content (Ciampa, 2017). Moreover, when literacy is integrated with science instruction to enhance rather than replace science inquiry, students show gains in science and literacy knowledge and processes (Casey et al., 2018; Odegaard et al., 2015).

Literacy also has a significant impact on the development of students' mathematical abilities. Studies have consistently found that learners with higher levels of comprehension tend to perform better in solving word problems (Öztürk et al., 2020; Pongsakdi et al., 2020; Fuchs et al., 2018). Literacy skills provide a strong foundation for learning mathematical concepts and problem-solving strategies (Pongsakdi et al., 2020). Koskinen and Pitkäniemi's (2022) study further proved that instruction focusing on conceptual comprehension produces better learning outcomes and more in-depth skills than the teaching weighted towards mechanical numeracy. Literacy skills, such as analysing and synthesising information, can also be applied to mathematical tasks (Salminen et al., 2021).

When students can read and write about mathematics topics, they can engage with the material on a deeper level and develop a broader understanding of the content knowledge (Salminen et al., 2021; Peng et al., 2020). Furthermore, literacy can help students develop a deeper understanding of mathematical concepts (Peng et al., 2020). It can increase confidence and success in maths (Salminen et al., 2021). Literacy and mathematical skills are closely connected and improving one can lead to improvement in the other. As such, it is essential to prioritise literacy development to enhance mathematical ability.

Incorporating literacy into science instruction can take many different forms. Since literacy is a powerful tool for engaging students' minds, fostering the development of conceptual understanding, promoting inquiry, and cultivating scientific ways of thinking (Fang & Wei, 2010), science and mathematics teachers should consistently integrate literacy while teaching. Teachers can incorporate reading and writing skills in writing lab reports or problem-solving skills (Pearson et al., 2010; Clark & Lott, 2017). Teachers can also have students create and present science-related projects using multimedia tools since scientific inquiry and literacy share similar processes that can be utilised to reinforce each other (Cervetti et al., 2012). Also, teachers can facilitate class discussions and debates to allow students to practise critical thinking and communication skills (Tolbert et al., 2014; Windschitl et al., 2020). Moreover, teachers can also assign research papers to students, allowing them to prove a hypothesis and enhance their scientific literacy skills since writing research papers require critical thinking, analysing data, and presenting information logically (Alt, 2018). Teachers can improve students' oral skills by incorporating technology into the assessment process, such as recording presentations and allowing students to reflect on their performance (Nikolic et al., 2018).

Assessing literacy for effective learning and teaching

Assessing literacy measures students' reading, writing, speaking, and listening skills (Munger., 2016). It can help identify students at risk with literacy difficulties so that teachers can provide them with the necessary support and intervention (Coombe et al., 2020). Further, it can help teachers understand students' needs and adapt their teaching activities to address them better (Berry et al., 2019). Teachers can design lessons and activities that target specific areas of improvement if they know their individual students' literacy strengths and weaknesses (Coombe et al., 2020). This process can lead to more effective instruction and improved student achievement. In addition, assessing literacy can provide baseline data for tracking progress and measuring the effectiveness of interventions (Giraldo, 2018). By regularly assessing literacy skills, teachers can monitor their student's progress and adjust their teaching methods as needed. It can help ensure that all students are making progress and reaching their full potential. However, there are also potential drawbacks to assessing literacy, including the potential for bias in the assessment process and the limitations of specific assessment methods. It is vital for teachers to be aware of these potential issues and to use a variety of assessment methods to get a holistic understanding of a student's literacy skills (Coombe et al., 2020).

There are several approaches to assessing literacy. The most common assessment type is standardised tests designed to measure literacy skills such as reading comprehension, vocabulary, and written expression (Stahl et al., 2019). Other studies also used classroom observation, where a trained professional observes students' literacy skills during regular class activities and notes their strengths and weaknesses (Afflerbach, 2017). Portfolio assessment is also used, which involves collecting a student's work over time and using it to evaluate their literacy skills (Marhaeni et al., 2018). Moreover, performance tasks require students to demonstrate their literacy skills in a real-world context (Mede & Atay, 2017). One-on-one assessments include individual reading-aloud activities or completing written tasks (Jefferies et al., 2018). Coombe et al. (2020) also reported various approaches to assessing language literacy. These include assessment to promote language learning, classroom assessment, integrated language assessment, content assessment, multilingual assessment, and multimodal assessment.

In a more general sense, assessment is theoretically and empirically supported as the central feature of effective learning and teaching (Black & Wiliam, 2018). When teachers use assessment, from in-class contingent formative assessment to the most formal summative assessment, including high stake tests (Davison, 2007), to engage students in assessment, higher learning outcomes are observed (Alt & Raichel, 2022). Similarly, when teachers use assessment data, ranging from individual students' data, including their social-emotional and achievement data, to school data (Beswick et al., 2022), they make better decisions to support individual students (Mandinach & Gummer, 2016). Although these processes are widely applied in science and mathematics learning, the intersections of assessing literacy and scientific and mathematical literacy are not well defined. A critical inquiry is lacking on how teachers assess literacy while simultaneously assessing science or mathematics content knowledge and skills and using the results to adjust their integration of literacy in teaching content knowledge.

Method

We used the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA) guidelines (Page et al., 2021) to answer our research questions. PRISMA is a widely used framework for reporting and synthesising literature review following four steps:

1. Identifying research literature from database searches;
2. Screening articles using inclusion and exclusion criteria;
3. Assessing full-text articles for eligibility; and
4. Coding and reporting the final articles included in the review.

Data sources and literature search

We accessed three electronic databases: Scopus, Web of Science, and ProQuest, to search for articles related to assessing literacy in science and math classrooms. These databases thoroughly cover the literature in education and various fields. There were no constraints on the articles searched regarding subject, discipline, or date. A consistent search string query with Boolean operators was used in all databases. While this study employed a strict search strategy, further rounds were carried out to explore the topic area beyond the research questions uncovered. As the familiarity with the literature developed, the basic search phrases were refined until the team decided to formalise the search string shown in Table 1.

Table 1: Search strategy syntax

Database	Keywords	No.
Web of Science	TS = ((literacy OR reading OR listening OR oral OR speaking OR writing) AND (student) AND (Science OR Math*) AND (“formative assessment" OR "summative assessment" OR “feedback” OR “self-assessment” or "peer assessment" OR "assessment for learning" OR "assessment of learning" OR "assessment as learning" OR “questioning” OR “classroom assessment” OR “teacher assessment”) AND (learning) AND ("high school" or primary or elementary))	161
Scopus	TITLE-ABS-KEY ((literacy OR reading OR listening OR oral OR speaking OR writing) AND (student) AND (Science OR Math*) AND (“formative assessment" OR "summative assessment" OR “feedback” OR “self-assessment” or "peer assessment" OR "assessment for learning" OR "assessment of learning" OR "assessment as learning" OR “questioning” OR “classroom assessment” OR “teacher assessment”) AND (learning) AND ("high school" or primary or elementary))	103
ProQuest	noft (literacy OR reading OR listening OR oral OR speaking OR writing) AND noft (student) AND noft (Science OR Math*) AND noft (“formative assessment" OR "summative assessment" OR “feedback” OR “self-assessment” or "peer assessment" OR "assessment for learning" OR "assessment of learning" OR "assessment as learning" OR “questioning” OR “classroom assessment” OR “teacher assessment”) AND noft (learning) AND noft ("high school" or primary or elementary)	419

The search query was designed to meet the demands of each database. The search produced 419 items from ProQuest, 103 articles from Scopus, and 161 articles from Web of Science. Additionally, the “snowball” method was used to find citations inside publications that seemed especially pertinent (Hepplestone et al., 2011). As a result, two more articles were found by this method.

Study selection

Figure 1 illustrates the multi-stage screening process for evaluating and selecting relevant studies identified in the search. The initial results indicated that the search strategy used in Stage 2 picked up many irrelevant articles. The search string query provided structure and conditional filtering studies from the selected databases. Also, a database-specific filtering mechanism using document type was employed to refine the results further, filtering only scholarly journals. Due to resource limitations, only those articles published in English were included. Information about the articles was imported and stored in Microsoft Excel, which was used to remove duplicates. There were no restrictions regarding the design of studies: quantitative, qualitative, or mixed methods. Studies were included if they broadly described literacy assessment in science and mathematics. Articles were included in this review if they were published in peer-reviewed journals in English.

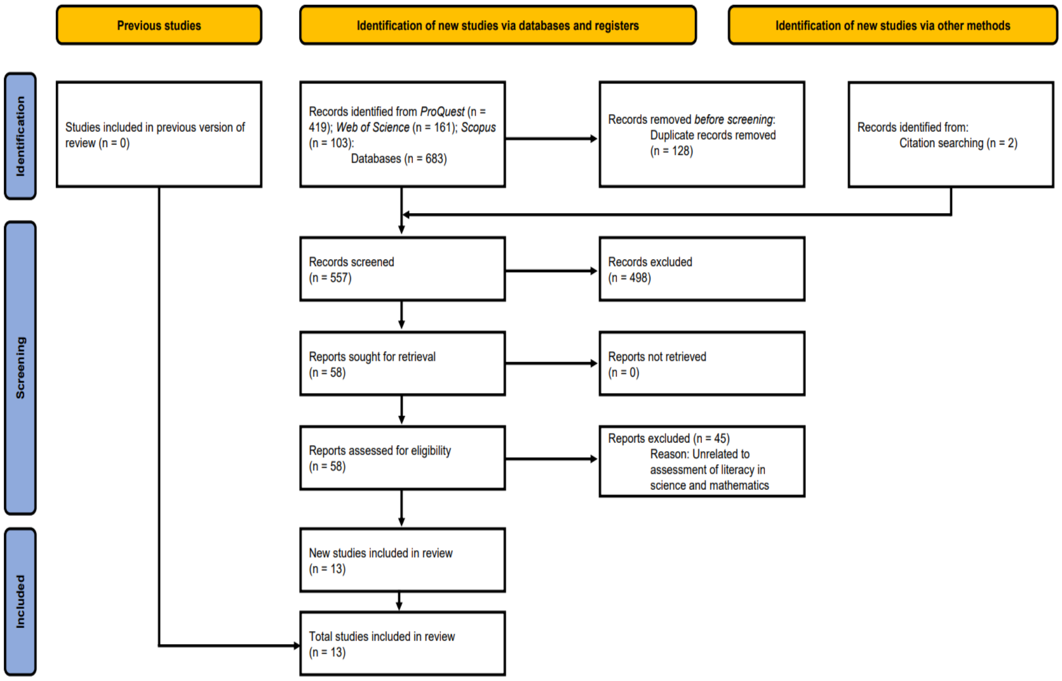

Figure 1: Study selection flow diagram
(Use web reader or PDF reader 'zoom in' function to read)

Accessing full-text articles

After the initial screening, the 58 relevant articles were downloaded for subsequent full-text review. The authors acknowledge that there were articles that were difficult to secure through the usual institutional holdings; as such, these articles were excluded from the first iteration of coding (n=2). However, attempts were made to contact the author or the journal to procure the article, but we have not received any reply.

Coding and reporting the results

The 58 full-text articles were reviewed to determine if there was clear information about assessing literacy in science and mathematics and approaches used to assess literacy in Science and Mathematics. The final analysis and synthesis excluded papers that did not include assessing literacy in science and mathematics. In addition, articles were excluded if the full text was presented in another language with only their abstracts in English. Following the same shortlisting and consensus-building process, 13 articles remained for qualitative evidence synthesis.

Three stages of thematic synthesis in systematic reviews, as highlighted by Thomas and Harden (2008), were used. These three stages are (i) coding text: the line-by-line coding;

(ii) developing 'descriptive' themes; and (iii) generating analytical themes. The first author developed descriptive and analytical themes that the second and third authors reviewed. Then, these themes and coding were reviewed again by all authors. The results of the thematic synthesis are presented in the following section.

Results

In this section, we present the results of our study following our two research questions.

RQ1: How is assessing literacy in science and mathematics reported in the literature?

Table 2 presents a summary of the 13 articles reviewed.

Table 2: Summary of studies (N=13)

Study	Country	School context	Research design/ data collection methods	Principal focus
Baiduri (2017)	Indonesia	Elementary (grade 5)	Mixed method design involving 24 students. Data related to spoken activities is collected through observation, field notes, and closed questionnaires, and the data related to student's responses is collected through interview.	Use of learning strategies
Biyik & Şenel (2019)	Turkey	Elementary (grade 4)	Quasi-experimental design involving 18 students in control group and 20 students in the experimental group via purposive sampling. The achievement test and the scientific process skills scale were given as pre-test and post-test; after 24 days from the administration of post-test, the achievement test was re-administered to measure retention levels.	Use of learning strategies
Cano et al. (2014)	Spain	Secondary (grade 9)	Descriptive survey involving 604 students from 35 science classes at 16 different schools, state and private, within a large urban area. Students will answer the questionnaire during regular class time.	Student learning
Freeman et al. (2016)	USA	Primary (aged 8-13-grade 3 to 8)	Descriptive-comparative design involving 42 students. Coding	Use of learning strategies

Glogger et al. (2012)	Germany	Secondary (grade 9)	Descriptive survey involving 236 students from 10 classrooms wrote learning journals in mathematics for over 6 weeks. Students worked on the pretest for 10 mins and filled in the SELLMO-S survey. Afterwards, students received introductory presentation on journal writing. Journal writing was assigned as weekly homework. After 6 weeks, journals were collected. A post test was conducted for 30 mins and students filled in a questionnaire on demographics, mental effort and open feedback.	Use of learning strategies
Haug & Ødegaard (2014)	Norway	Elementary (grade 4 and grade 5)	Qualitative video study (2 volunteer teachers handling Grade 4 and Grade 5 students). Data were collected through video recordings of the teachers handling the class using the Seeds/Roots curriculum.	Use of learning strategies
Hofstein et al. (2005)	Taiwan	Senior high school	Quasi-experimental design involving 40 students. Students will conduct experiments that are largely confirmatory by technology. Then they will be doing the inquiry activities. The questioning will be evaluated by four experts (technology educator and experienced teachers) who were asked to define them according to low level and high-level type questions.	Student learning
Kinniburgh & Baxter (2012)	USA	Elementary (grade 4)	Descriptive survey involving 10 pupils. Students were homogeneously grouped by ability and changed classes throughout the day to compare results of pre-test and post-test during the 4-week implementation period.	Use of learning strategies
Lai & Chan (2020)	Taiwan	Elementary (grade 5)	Quasi-experimental design involving 59 students in the experimental group and 59 students in the control group.	Use of learning strategies
Malepa-Qhobela & Mosimege (2022)	South Africa	Secondary (grade 10)	Qualitative multiple case study involving 5 teachers handling Grade 10 mathematics. Data were generated through an open-ended questionnaire, semi-structured interviews, and lesson observations.	Use of learning strategies
Martin et al. (2017)	USA	Elementary (grade 4)	Case study design involving 8 students. Data were collected through observations, field notes, audio recordings, conference notes, and students' journal researchers' journals; used thematic analysis and open coding.	Use of assess-ment

Román et al. (2019)	USA	Primary and secondary	Qualitative design involving 2 teachers handling 1 elementary science class, 26 students; and 1 middle school science class,27 students. Data were collected through classroom observations, videos of instruction, and student and teacher interviews.	Use of assessment
Smith et al. (2019)	USA	Primary (grade 4 to 5)	Descriptive design involving 95 students. Coding of students written responses	Use of assessment

Countries

Most of the research on assessing literacy in science and math classrooms was conducted in Western countries, including the USA (n=5), Norway (n=1), Spain (n=1), Germany (n=1), and South Africa (n=1). There were also studies from Asia, which includes Taiwan (n=2), Indonesia (n=1), and Turkey (n=1).

School context

Most studies reviewed focused on primary school (n=7), which ranges from Year 4 (Biyik & Şenel, 2019; Kinniburgh & Baxter, 2012; Martin et al., 2017), Year 5 (Baiduri, 2017; Lai & Chan, 2020), and Years 4 and 5 combined (Haug & Ødegaard, 2014; Smith et al., 2019). Some studies focused on both primary and high school (n=2). These studies did not mention the specific year levels (Román et al., 2019). The other study used students ages 8 to 13, typically Years 3 to 8 (Freeman et al., 2016). Some studies focused on junior high school (n=3), involving Year 9 and 10 middle school students (Cano et al., 2014; Glogger et al., 2012; Malepa-Qhobela & Mosimege, 2022). Only one study focused on senior high school students (Hofstein et al., 2005).

Research design

Out of the 13 studies, 8 used quantitative, four used qualitative, and one used a mixed-method design (Table 2). For quantitative designs, the studies were primarily descriptive surveys (Cano et al., 2014; Glogger et al., 2012; Kinniburgh & Baxter, 2012; Smith et al., 2019; Freeman et al., 2016) and quasi-experimental (Biyik & Şenel, 2019; Hofstein et al., 2005; Lai & Chan, 2020), where data were collected through questionnaires. Two qualitative studies relied on video analysis (Haug & Ødegaard, 2014; Román et al., 2019). The data were collected through video recordings of the teachers while teaching and student and teacher interviews (Haug & Ødegaard, 2014; Román et al., 2019). Other studies also collected students' responses in a blog (Freeman et al., 2016). Two case studies obtained data from actual observations, audio recordings, journals, and field notes (Martin et al., 2017; Malepa-Qhobela & Mosimege, 2022). Only one study used a mixed-method design where data was collected through questionnaires, field notes, observation, and interviews (Baiduri, 2017).

Principal focus

Two research foci emerged from the 13 articles, namely (a) teaching practices (n=11) and student learning (n=4).

Teaching practices focus

Teaching practice is defined as how teachers use strategies to assess learning in the classroom. Out of the ten articles that focused on teaching practices, seven studies had research focused on the *use of learning strategies* that would help in building literacy in learning science and mathematics concepts. For example, using the question-answer relationship strategy increases reading comprehension in science content materials (Kinniburgh & Baxter, 2012). Also, the use of question-answer relationship enabled students to develop their problem-solving skills in mathematics (Malepa-Qhobela & Mosimege, 2022). Another study also focused on how multimodal writing affects students' communication skills in learning mathematical ideas (Freeman et al., 2016). Another study also analysed the use of learning journals in predicting learning outcomes in maths (Glogger et al., 2012). One study also describes how peer tutoring methods develop students' verbal abilities in mathematics (Baiduri, 2017). One study determined the effect of writing science notebooks on the development of science process skills, retention levels, and academic achievement (Biyik & Şenel, 2019). A study also integrated science trade book reading into science learning (Lai & Chan, 2020). Moreover, one study explored how teachers facilitate conceptual understanding through inquiry-based strategies (Haug & Ødegaard, 2014). The second group of studies (n=3) focused on using assessment to develop literacy in science and mathematics concepts. One study explored teachers' informal formative assessment practices as they engaged with the students in constructing science explanations (Román et al., 2019). The other used a multimodal assessment framework to assess students' writings and drawings (Smith et al., 2019). The last study explored how students used writing to evaluate their learning and how the teacher used the students' written reflections as a formative assessment for instructional purposes (Martin et al., 2017).

Student learning focus

Student learning refers to the measurable knowledge and skills gained after exposure to a particular instructional approach. Two studies focused on how student learning is developed as teachers develop the student's literacy in learning science and mathematics concepts. One study developed a test path model that would explain the relationship between how students learn in science classrooms, ask questions, and comprehend, which would result in learning achievement in science (Cano et al., 2014). Another study focused on the ability of students to ask meaningful and technologically sound questions related to their observations after critically reading a technology article (Hofstein et al., 2005).

RQ2: What approaches are used to assess literacy in science and mathematics?

Macro skills

Four macro skills are present in the articles, including writing (n=5), reading (n=3), speaking (n=6), and listening (n=1). Most of the studies assessed the writing activities of students in their science notebooks (Biyik & Şenel, 2019), learning journals (Glogger et al., 2012), reflection journals (Martin et al., 2017), drawings with discussions of conceptual knowledge (Smith et al., 2019), and student's discussions in their notepads and blog (Freeman et al., 2016). Furthermore, other studies assessed reading comprehension and its relationship to the student's learning achievement (Cano et al., 2014), question answer relationship as observed in the student's reading level of the comprehension passage (Kinniburgh & Baxter, 2012), ability to understand and solve maths problems (Malepa-Qhobela & Mosimege, 2022), and student's reading strategies in reading science trade books (Lai & Chan, 2020). One study assessed the student's speaking skills as manifested in their ability to ask a question and actively participate in the discussions during their peer tutoring sessions (Baiduri, 2017). Another study also assessed question-asking skills and their relationship to reading comprehension (Cano et al., 2014). Moreover, one study also assessed the student's ability to explain their conceptual understanding of the topics presented (Haug & Ødegaard, 2014). Further, other studies measured students' inquiry skills as manifested in how they ask questions during laboratory activities (Hofstein et al., 2005) and how students interact with the teacher during class discussions (Román et al., 2019). Moreover, Roman et al. (2019) also assessed the students' listening skills as teachers interacted with them, as shown in how they shared their queries and ideas with the teacher.

Subject area

Eight of the included articles focused on science (Biyik & Şenel, 2019; Cano et al., 2014; Haug & Ødegaard, 2014; Hofstein et al., 2005; Kinniburgh & Baxter, 2012; Lai & Chan, 2020; Román et al., 2019; Smith et al., 2019) and only five are focused on mathematics (Baiduri, 2017; Glogger et al., 2012; Martin et al., 2017; Freeman et al., 2016; Malepa-Qhobela & Mosimege, 2022).

Assessment tools

Most studies used questionnaires (n=6) to assess literacy in science and maths concepts. Other studies used observations and field notes (n=3) and journals (n=4), to determine students' learning achievement while being exposed to a teaching strategy. Other studies used oral presentation (n=3) in assessing the learner's abilities in question-asking, discussing concepts and problem-solving skills. One study used the blog to determine students' understanding of the concepts being taught.

Assessment strategy used

The assessment strategies present in the 13 included articles were grouped into: (a) formative assessment (n=9), (b) summative assessment (n=2) and used both assessment approaches in teaching (n=2). Formative assessment refers to the methods used by teachers in conducting in-process evaluations during the lesson. Most studies used a formative assessment strategy to assess students' literacy skills during classes. For example, one study used the peer tutoring method, where the tutor and the tutees openly discussed their ideas during group discussions (Baiduri, 2017). Formative assessment is also used in students' writing activities as characterised by how they solve problems and questions, communicate with their classmates collaboratively, write information, and make presentations after performing the activities (Biyik & Şenel, 2019). In addition, formative assessment is used to evaluate students' ability to ask questions during class (Cano et al., 2014), measure how students explain concepts presented during class (Haug & Ødegaard, 2014), and how they ask questions during laboratory activities (Hofstein et al., 2005). Another study used formative assessment to read aloud the passage and answer the comprehension question (Kinniburgh & Baxter, 2012). Lai and Chan (2020) used formative assessment to read science trade book activities, conduct scientific experiments, draw mind maps, and discuss students' ideas within the group. Roman et al. (2019) also used formative assessment to assess how the students interact with the teacher after being asked a question. One study also used formative assessment to assess student's question and answer skills and problem-solving skills (Malepa-Qhobela & Mosimege, 2022).

Meanwhile, teachers use summative assessments to evaluate students' understanding of the concepts, usually conducted at the end of the unit. For example, learning journals are used by teachers to assess the comprehension levels of students and how they link new concepts to their prior knowledge (Glogger et al., 2012). Journals are usually written after each class as a monitoring tool for students' understanding of the lessons. Another study also assessed the student's writings and drawings of the concepts presented to them (Smith et al., 2019). There are studies also that used both formative and summative assessment strategies to evaluate students' literacy in their classes. For example, a workshop model in which mini-lessons are conducted allows the students to interact with the class. The students write reflections after the lessons (Martin et al., 2017) and use social maths blogs where students collaborate with their classmates during discussions and use notepads to write their answers after the class (Freeman et al., 2016).

Reported outcomes

Two key concepts emerged in the reported outcomes of the 13 articles included. The reported outcomes are grouped into: (a) assessment strategies increased student's learning outcomes; and (b) teachers as critical players in assessing.

Assessment strategies increased students' learning outcomes

Assessment strategies are used to determine students' progress and use the information to plan the succeeding learning and teaching activities. A well-designed assessment provides valuable information about what students learned, how well they learned, and where they struggled. Teachers can use this information to decide which teaching activities best improve student learning. Of the articles included, seven papers highlighted the impact of assessment on improving student learning outcomes. Baiduri (2017) reported that peer tutoring developed students' speaking skills, manifested in their agency and ability to ask questions and actively participate in the discussion. In addition, using question-answer relationship strategy improved students' speaking skills (Kinniburgh & Baxter, 2012). Cano et al. (2014) added that a relationship exists between students learning in science and their question-asking ability in the classroom. Further, integrating writing and drawing into the lessons, such as using science notebooks (Biyik & Şenel, 2019; Smith et al., 2019), notepads (Freeman et al., 2016), and learning journals (Glogger et al., 2012) improve both literacy and scientific knowledge. Reading is also incorporated into the lessons through science trade books (Lai & Chan, 2020). These strategies contribute to higher academic achievement, which is evident in the student's improved reading, writing, and speaking abilities. These assessment strategies reflect students' understanding of the lessons and provide opportunities for students to self-evaluate their progress (Martin et al., 2017).

Teachers as crucial players in literacy assessment

Teachers' role in students' learning ensures they acquire the desired knowledge and skills. They also decide and plan which learning strategy best fits the lesson to the type of learners. For example, in Baiduri's (2017) study, peer tutoring was used to identify students' speaking skills. The teacher's crucial responsibility is to choose a competent tutee to assist in teaching. In the inquiry process, the teacher facilitates scaffolding the students' use of language (Haug & Ødegaard, 2014). The teacher also acts as a facilitator in teaching problem-solving skills in mathematics (Malepa-Qhobela & Mosimege, 2022). The teacher gives feedback to the students on what to do and assists them in carrying out the writing, speaking, listening, and reading activities (Hofstein et al., 2005). In addition, conducting assessment involves eliciting and interpreting information to promote student learning. For this process to be effective, teachers must be knowledgeable enough to plan, develop and implement these activities to make learning and teaching successful (Román et al., 2019). In addition, teachers must have knowledge of the types of feedback and when to provide it to ensure that effective learning is taking place (Wong et al., 2018). These findings indicate that successful learning and teaching in science and mathematics depends on how well teachers use assessment strategies, depending on their assessment knowledge and skills.

Challenges

Only four studies reported challenges in assessing students' literacy in science and mathematics. One study discovered that teachers encounter challenges in integrating the question-answer relationship strategy into problem-solving activities due to its time-intensive nature (Malepa-Qhobela & Mosimege, 2022). Teachers expressed concerns that facilitating student dialogue and involvement in the problem-solving process requires significant time, particularly considering variations in learning pace among students within the classroom. One study found that using learning journals in assessing learning is not always practical, as some unmotivated students struggle to write their thoughts and insights (Glogger et al., 2012). Students have different strengths and weaknesses, and not all students like writing. These poorly written journals hinder teachers in determining authentic learning because their outputs do not holistically reflect their understanding.

Students with poor learning experiences can also have difficulty implementing these assessment strategies (Kinniburgh & Baxter, 2012; Román et al., 2019). Thus, teachers should consider their students' abilities, prior knowledge, and skills before assessing to optimise results. For example, drawing activities to assess student learning in science or mathematics may not always be practical for students with poor drawing skills. This situation becomes more difficult for teachers handling heterogeneous, multigrade, and special education classes, where students have various skills, interests, and prior learning experiences. These challenges suggest that teachers must carefully consider the assessment strategy that will be used since students have different skills and learning backgrounds.

Discussion

Based on the findings, this paper provides a synthesis of how assessing literacy in science and mathematics is researched and reported. There are noteworthy findings that emerged in this paper. First, in assessing literacy in science and mathematics classrooms, writing (e.g., Glogger et al., 2012; Martin et al., 2017) and speaking (e.g., Cano et al., 2014; Baiduri, 2017; Malepa-Qhobela & Mosimege, 2022) skills were more popular skills being assessed than listening and reading. Listening skills are the least explored (Román et al., 2019). This apparent gap in assessing listening and reading in science and mathematics classes presents an opportunity for further inquiries.

Second, formative assessment has been used in most studies, more than summative assessment. Formative assessment strategies that were reported included peer assessment (Baiduri, 2017), questioning (Cano et al., 2014; Hofstein, 2005; Kinniburgh & Baxter, 2012; Román et al., 2019), and feedback (Biyik & Şenel, 2019). Although these assessment strategies have been proven effective in increasing student outcomes (Black & Wiliam, 2018), other strategies can be used. These include self-assessment (Yan et al., 2020), sharing learning outcomes and success criteria (Jones et al., 2017), and the use of exemplars (Handley et al., 2013). It would be worthwhile to explore how these assessment strategies can be used to assess literacy in science and mathematics classrooms and use the assessment data to further support the literacy needs of students.

Third, we have also found the critical role of teachers' assessment knowledge and skills in assessing literacy while assessing science and mathematics content knowledge and skills. The impacts of teachers' assessment activities on student learning depend primarily on their ability to plan (Baiduri, 2017) and use assessment to effectively support individual students (Haug & Ødegaard, 2014). Teacher feedback practices are one of the most effective skills (Hofstein et al., 2005). Teachers' ability to analyse assessment data assists them in making decisions on how to effectively adapt and implement learning and teaching activities (Alonzo et al., 2021; Román et al., 2019). What is not reported is the specific assessment knowledge and skills teachers need to have to effectively assess students' literacy in the science and mathematics classroom. We need more studies to demonstrate if the simultaneous assessment of literacy and content knowledge requires more sophisticated assessment knowledge and skills, considering the intersections between literacy, content knowledge and assessment.

Fourth, limited studies (n=4) reported some challenges in assessing literacy while assessing science and mathematics content knowledge and skills. The challenges are focused mainly on students' motivation, prior knowledge and ability (Kinniburgh & Baxter, 2012; Román et al., 2019; Malepa-Qhobela & Mosimege, 2022), and involvement in assessment (Glogger et al., 2012). Given the limited number of studies included in this paper, it is inconclusive if there are other factors that influence teachers' ability to assess literacy in this context. More in depth-studies exploring the challenges and limitations of assessing literacy in science and mathematics classrooms will be worthwhile to conduct to provide greater insights for practical and theoretical perspectives.

Fifth, it was apparent that teachers and students must be assessment literate to perform their responsibilities actively. Ensuring that teachers have a high level of assessment literacy, that is, their knowledge and skills in using assessment to make highly contextualise and fair assessment decisions to support student learning (Alonzo, 2020) effectively, would optimise the impact of their assessment practices in increasing student literacy and content knowledge. Teachers' primary role is to develop assessment tools that assess literacy and content knowledge and use them, and the assessment data gathered to adapt their learning and teaching activities (Mellati & Khademi, 2018). The goal of teachers is to use assessments that provide a comprehensive and accurate picture of individual students' knowledge, skills, and abilities and to use that information to guide instruction and support student learning (Kulasegaram & Rangachari, 2018). Thus, successful classroom learning dramatically depends on teachers' ability to use appropriate assessment strategies (Alonzo et al., 2021). Similarly, student assessment literacy, their understanding of assessment principles and practices and their ability to engage in assessment (Hannigan et al., 2022) would increase their motivation and, consequently, their learning outcomes. They need to engage actively and take responsibility for their learning. It includes setting learning goals, seeking out and using resources, asking questions, participating in group discussions, and reflecting on their progress. However, students are not born with assessment literacy. Teachers must develop students' assessment literacy before engaging them in the assessment process (Alonzo & Loughland, 2022). This also raises an issue about the quality of pre-service training in assessment (Oo et al., 2022; 2023).

Taking the findings as the emerging body of knowledge relating to assessing literacy in science and mathematics, our review has identified significant geographical, practical, and theoretical gaps. Among these studies, almost half were conducted in the USA, while only one each was from Norway, Spain, Germany, Indonesia, and Turkey. We need more studies from other countries to see contextual and policy influences in this area of inquiry. In addition, previous research highlighted that integrating literacy in key learning areas, including science and mathematics, helps students improve their content knowledge and engagement in these subjects (Herlanti et al., 2019; Öztürk et al., 2020). However, only 13 relevant articles were extracted from three databases, indicating limited research in this area. In addition, no comprehensive framework defines the intersections of assessing literacy of science and mathematics, although science, mathematics, and literacy are interconnected and mutually beneficial (Pearson et al., 2010; Clark & Lott, 2017; Peng et al., 2020). The framework may serve as a starting point for rethinking how assessing literacy in science and mathematics can be fully implemented to optimise its impact on increasing student literacy skills while learning the content knowledge and skills. This framework may also guide teachers to reflect on their practices and identify areas for further improvement.

Conclusion and limitations

We aimed to develop a knowledge base that will guide teaching practices and future research in assessing literacy while simultaneously assessing science and mathematics content knowledge and skills. We reported the characteristics of studies reviewed, the macro skills assessed, assessment tools and strategies used, and the impact on students' learning. Our study also reported several challenges encountered by teachers. The small number of studies reported limited our attempt to develop a comprehensive knowledge base on the intersections between assessing literacy and science and mathematics content knowledge. The emerging knowledge base relating to this inquiry presents opportunities for future research, including finding ways to effectively assess literacy, engaging students, supporting teachers and developing practical knowledge for this particular context of assessment use.

Our study has few limitations to declare. In our attempt to include only studies that we deemed rigorous, our exclusion criteria (exclude book, book sections, report, and other grey literature) may have limited our search. This review may only represent some empirical research with complete disregard to other literature that might have clearer theorisation of the intersections of literacy, assessment and science and mathematics content knowledge and skills. In addition, we did not explore other key learning areas, which might have better theorisation of assessing literacy in a particular content knowledge.

Disclosures

Funding details
No funds, grants, or other support was received.
Disclosure statement
The authors report there are no competing interests to declare.
Ethics statement
No ethical approval was required for this study, as all data were retrieved and synthesised from published studies.
Data availability statement
The manuscript has no associated data as this is a review paper.

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Please cite as: Sarsale, J., Alonzo, D., Caseñas, A., Oo, C. Z., Sy, F. A. & Yepes, P. I. (2024). Assessing literacy practices and futures in science and mathematics classrooms: A systematic review. *Issues in Educational Research*, 34(2), 719-742.
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