European Journal of Science and Mathematics Education
Vol. 5, No. 3, 2017, 285-284

Research on mathematical literacy in schools - Aim, approach and attention

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Abstract

The development of mathematical literacy in schools is of significant concern at the policy level, and research is an important source of information in this process. This review article focuses on areas of research interest identified in empirical projects on mathematical literacy, and how mathematical literacy in schools is approached by research. The following three main challenges are identified: both researchers and teachers are uncertain about how to develop students' mathematical literacy, specific attempts to work directly with mathematical literacy through mathematics alone have not been successful, and teaching for mathematical literacy appears to require non-traditional methods for teaching mathematics. More qualitative research is called for, with emphasis, for example, on classroom studies focusing on teachers' priorities regarding mathematical literacy, best-practice examples, or interventions in which teachers and researchers work together.

Keywords: mathematical literacy, review, empirical research

Introduction

Mathematical literacy is one of the key competencies highlighted by the Organization for Economic Cooperation and Development (OECD) (2005, 2009), and is described as follows:

> an individual's capacity to identify and understand the role mathematics plays in the world, to make well-founded judgements and to use and engage with mathematics in ways that meet the needs of that individual's life as a constructive, concerned and reflective citizen (OECD, 2003, p. 15).

Mathematically literate students are able to analyse, reason, and communicate ideas effectively as they pose, formulate, solve, and interpret solutions to mathematical problems in a variety of situations and contexts (OECD, 2009, 2012). These contexts range from being purely mathematical to having no mathematical structure present or apparent at the outset and requiring the solver to introduce the mathematical structure. The definition concerns doing and using mathematics in situations that range from the everyday to the unusual and from the simple to the complex (OECD, 2009, 2012). Hence, development of students' mathematical literacy will influence their confidence and competence in mathematics and prepare them for the application and future learning of mathematics in higher education and outside of the classroom (OECD, 2003).

Mathematical literacy is one of the competencies measured through Programme for International Student Assessment (PISA) tests. PISA tests are comparative international tests aimed at assessing how well education systems prepare students for real life situations. PISA tests seek to assess the ability of 15-year-old students to apply what they have learned in school to non-school environments. Much of the research in the mathematical literacy field uses results from worldwide or national PISA tests that emphasize mathematical literacy in order to focus on implications for national school and social matters. However, some research focuses directly on mathematical literacy and teaching for mathematical literacy, and the research community is urged to focus on this approach: "The question of how to teach for mathematical literacy must be theoretically and empirically studied. When we consider the urgency of the issue, we should make sure that such research is given high priority" (Sfard, 2014, p. 141). An examination of priorities in the attention that research gives to mathematical literacy in teaching and learning will assist in addressing implications that arise for primary and lower secondary school teaching and for future research on mathematical literacy. However, no comprehensive review of current empirical research on the priorities within mathematical literacy research has been conducted.

This review article focuses on areas of research interest in empirical projects where mathematical literacy is highlighted. It includes quantitative and qualitative projects, studies in which mathematical literacy is emphasized in the development of data collection tools or in what is being measured, and studies that focus more on teachers' implementation of mathematical literacy in teaching and learning. The article aims to address research on mathematical literacy in primary and lower secondary school by bringing together and synthesizing the diverse body of current research, emphasizing the implications for teaching in the area, and pointing to areas that need to be addressed in future research. Within these parameters, we aim to present a systematic review of recent empirical studies, focusing on the following four key questions:

1. *How is mathematical literacy conceptualized?*
2. *What methods have been used to examine emphasis on mathematical literacy in primary and lower secondary school?*
3. *What is the focus of attention in research on mathematical literacy?*
4. *What are the implications for primary and lower secondary school teaching, and recommendations for future research on mathematical literacy?*

Method

Review parameters

One of the first written occurrences of the term *mathematical literacy* was given by the Commission of the National Council of Teachers of Mathematics (NCTM) in 1944 in the United States (Niss & Jablonka, 2014). The NCTM stated that the school should ensure mathematical literacy for all who can achieve it, but did not provide a definition of the concept. According to Niss and Jablonka there is no universally accepted meaning of mathematical literacy, and a number of related notionscan be found in the mathematics education literature. Some authors use mathematical literacy, numeracy and quantitative literacy synonymously, while others distinguish between them. Other related concepts include critical mathematical literacy, mathemacy, matheracy and statistical literacy (Niss & Jablonka, 2014).

The OECD (1999) appears to have given the first explicit definition of mathematical literacy (Niss & Jablonka, 2014) and to a large extent, researchers define this concept as competence in accordance with the OECD definitions (1999, 2003, 2009, 2012).De Lange (2003) defined mathematical literacy as the comprehension and application of mathematics through reasoning, thinking and interpreting. Recently, other definitions of mathematical literacy have been attempted (Colwell & Enderson, 2016); however, within mathematics education research, there seems to be wide agreement that mathematical literacy is a person's ability to engage in higher-order thinking skills specific to mathematics that allow the understanding and application of mathematics in real-life, everyday situations. Mathematical literacy is the ability to make use of mathematical knowledge, the ability to pose and solve mathematical problems in a variety of situations and the motivation to do so (OECD, 2003). There seems to be general consensus about the definition of the concept of mathematical literacy within research on mathematics teaching and learning, but there is uncertainty about what is emphasized in the interpretation of the OECD definition and about how it is applied to students' development of mathematical literacy. Therefore, in the present review, we studied the use of the mathematical literacy concept in various publications to identify appropriate keywords for the selection of relevant literature.

The selection process for the review consisted of three phases. In the first phase, we identified keywords related to mathematical literacy in domestic and international policy documents(e.g., Kunnskapsdepartementet, 2015; OECD, 2003, 2005; OECD, 2009), and in books and anthologies focusing on mathematics education (e.g., Bishop, Clements, Keitel, Kilpatrick, & Leung, 2003; Pitici, 2014). In the second phase, we searched education databases (*ERIC, Scopus, Science Direct*) and the *Web of Science* citation database. The searches were limited to articles in English published after OECD launched the high impact *Definition and Selection Of Key Competencies* (DeSeCo) report (Allerup, Lindenskov, & Weng, 2006; OECD, 2005), which means articles published from 2006 onwards, using only the key term "mathematical literacy". Because of the current high level of attention paid to this topic, we anticipated that it would be necessary to include the additional keywords identified in the first phase in our search, such as "school", "teach", "education" or "problem-solving". This proved to be incompatible with our aim of reaching the body of article publications from the international mathematical literacy research community. The searches were simply narrowed down too much by the addition of even one keyword to the main term "mathematical literacy". In the third phase, we removed duplicate articles, articles that were not empirical studies, articles that focused on higher education or on the upper secondary school level, and articles that were not published in peer-reviewed journals. The resulting 28 publications form the basis of this review (see Appendix 1).

Analysis

We opened the process of analysis by dividing the articles between all three authors. We used a summary table for each of the articles, outlining each article's focus, setting (type of school and number of participants), methods and data sources, and identifying the implications of teaching for mathematical literacy in the reported research and subsequent implications for further research on mathematical literacy. The first author then combined these details into a single table and checked for inconsistencies or missing information. A brief summary of each article is shown in Annex 1. The conceptualization and application of a "mathematical literacy" definition in each article was identified and summarized. Factors that were considered to be influential in teaching for mathematical literacy were identified and categorized, as were identified implications and challenges related to the emphasis on mathematical literacy in school.

Results

Conceptualization of mathematical literacy

Most of the articles studied in this review refer to PISA tests and OECD definitions of mathematical literacy (OECD, 1999, 2003, 2009, 2012). Several of the articles use data from PISA test results, and are therefore obliged to acknowledge the prevailing OECD definition at the time of testing, because the attention to mathematical literacy in the PISA tests is based on this definition. Some of the articles do not provide an explicit definition of mathematical literacy (e.g., Areepattamannil, 2014; Jürges, Schneider, Senkbeil, & Carstensen, 2012; Roth, Ercikan, Simon, & Fola, 2015; Ryan, 2013; Yılmazer & Masal, 2014). However, because they either refer to PISA testing, or use PISA test results as data samples, it is presumed they used the prevailing OECD definition at the time to represent their notion of the concept. Such a perspective verifies the use of the data collected and analysed by others to analyse the effects and implications of PISA data for domestic development (Koğar, 2015; Lin & Tai, 2015).

In addition, some of the articles reviewed connect subject matter theories within mathematics education with the concept of mathematical literacy. A common factor for these articles is their interest regarding the teaching of mathematical literacy in school. Andrews refers to Kilpatrick, Swafford and Findell's (2001) five strands of mathematical proficiency—conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition—and point to their alignment with "PISA's key objective, with respect to mathematical literacy, of assessing students' application of mathematical knowledge and skills to authentic settings, both within mathematics itself and more broadly"(Andrews, 2013, p. 189). Höfer and Beckmann (2009) refer to Jablonka (2003), who relates mathematical literacy to the following five elements: developing human capital, cultural identity, social change, environmental awareness, and evaluating mathematics. According to Höfer and Beckmann, "the core of mathematical literacy is formed by the ability to apply mathematical knowledge to various and context-related problems in a functional, flexible and practical way" (p. 224). Meaney (2007) applies a different approach. Rather than focusing on what mathematical literacy is, she uses Kaiser and Willander's (2005) hierarchy of levels of mathematical literacy as the framework for research on recognizing and teaching mathematical literacy. These levels are illiteracy (ignorance of basic mathematical concepts and methods), nominal literacy (minimal understanding of mathematical terms and topics, accompanied by naïve theoretical explanations and misconceptions), functional literacy (use of procedures for solving simple problems, but restricted to very specific contexts and lack in-depth understanding), conceptual and procedural literacy (some understanding of the structure and function of central mathematical ideas), and multidimensional literacy (contextual understanding of mathematics incorporating philosophical, historical and social dimensions); all of these levels refer to students' understanding and use of mathematical concepts. Gatabi, Stacey, and Gooya (2012) apply yet another approach, when they relate mathematical literacy to a single concept within mathematics. They see mathematical modelling as the key process in mathematical literacy. Mathematical modelling starts with an extra-mathematical world problem. The solver then has to formulate the problem in mathematical terms, solve it by applying mathematical concepts and procedures, interpret the solution to provide an answer, and check the answer for adequacy in answering the original question. Such an interpretation is supported by Edo, Hartono, and Putri (2013), who also closely relate mathematical literacy to modelling, but on three levels. Hence, they increase the complexity of the relation between modelling and mathematical literacy.

They define mathematical literacy as an individual's capacity to formulate, employ and interpret mathematics. To *formulate* involves recognizing and identifying opportunities to use mathematics, providing mathematical structure to a problem presented in some contextualized form. To *employ* involves applying mathematical concepts, facts, procedures, and reasoning to solve mathematically formulated problems and obtain mathematical conclusions. Finally, to *interpret* involves reflecting upon mathematical solutions, results or conclusions and interpreting them in the context of real-life problems.

To summarize, the nuancedyet continuous development of the mathematical literacy definition given by the OECD seems to prevail within research on mathematical literacy, but researchers also show that they need to go beyond, or rather beneath, this definition when researching mathematics classroom activity. This seems to be because of the complexity of the prevailing OECD definition. It frames widely, and the researchers (and teachers) need to narrow the focus to only a few of the features of the OECD mathematical literacy concept to identify teaching development, change or impact on learning. For instance, Gatabi et al. (2012) found it necessary to closely relate mathematical literacy to mathematical modelling.

Overview of research methods

As stated in the introduction, one question of interest in this article relates to the methods used to examine mathematical literacy. To answer this question, the selected articles were categorized according to the countries in which the different studies were conducted, their methodological approach, the nature and size of the sample, and the source of the data.

Table 1. Data collection by country

Country	Number of data samples from each country
Turkey	6
Belgium**	3
Taiwan	3
Australia*	2
Finland**	2
Germany	2
Indonesia	2
Israel	2
USA	2
Canada	1
China	1
Czech	1
England**	1
Hungary**	1
India	1
Iran*	1
New Zealand	1
Spain**	1
Sweden**	1
Total	34

* One study was carried out in both Iran and

Australia.
** One study was carried out in England, Finland, Belgium, Hungary, Spain and Sweden.

The studies were conducted worldwide, but with a clear majority of European and Asian contributions. Studi
es on mathematical literacy in primary and lower secondary school from nine European and six Asian countries were represented in the articles reviewed. In addition, studies were reported from both Oceania and North America. As indicated in Table 1, the largest group of studies (six) were conducted in Turkey. The strong representation of OECD countries is of course influenced by the explicit attention given to PISA tests in these countries since the first PISA test cycle in 2000.

Table 2. Methodological approaches and sample sizes

Sample size	Actual range	Qualitative	Quantitative	Mixed methods	Number of studies
Fewer than 50	3–48	3	1	2	6
50–199	71–107	2	2	1	5
200–1000	213–897	1	3		4
Morethan 1000	1227–1,695,233		13		13
Total		6	19	3	28

A clear predominance of quantitative methodological approaches (more than 67% of studies) was observed (see Table 2). Studies categorized as mixed methods used both qualitative and quantitative sources of data. In the studies that use data collected from informants, the sample sizes varied from 3 to 1,695,233. The informants were students, teachers and teacher educators. Content analysis of mathematics text-books was also represented in the body of articles (Gatabi et al., 2012) (see Tables 2 and 3).

Table 3. Data sources

Type of data source	Number of studies
PISA	13
Knowledge tests	11
Interviews	7
Video study	4
Text-books	1
Intervention	1
Questionnaire	1

The studies used a variety of approaches (see Table 3). The vast majority of studies analysed PISA test results, and the development, implementation and evaluation of knowledge tests (often described as PISA-like tasks), which provided descriptive information on the impact of students' level of mathematical literacy, parameters influencing or influenced by students' mathematical literacy, or consequences of students' mathematical literacy level for society. One study collected data through Trends in International Mathematics and Science Study (TIMMS)-like tasks (Zikl, Havlíčková, Holoubková, Hrníčková, & Volfová, 2015). The qualitative data were primarily interviews and video studies of teaching sequences. Three video studies emphasized teaching and one focused on student activity. In addition, the body of reviewed articles contained an intervention study (Tzohar-Rozen & Kramarski, 2013), a document study (Gatabi et al., 2012), and a quasi-experimental study combining student knowledge tests with questionnaires (Chen & Chiu, 2016) to collect data.

Focus of attention in research on mathematical literacy

First, some researchers seemed to use mathematical literacy as a way to catch the reader's eye(Van Hoof, Janssen, Verschaffel, & Van Dooren, 2015; Van Hoof, Vandewalle, Verschaffel, & Van Dooren, 2014; Zhao, Valcke, Desoete, Verhaeghe, & Xu, 2011). We have reached such a view because we find it hard to argue for using mathematical literacy as a keyword or in the opening sentence of an article when the concept does not appear elsewhere in the article. Perhaps this is due to the wide and varied definitions of mathematical literacy given by the OECD (1999, 2003, 2009, 2012). Second, the research articles studied in this review show that research on mathematical literacy is dominated by quantitative approaches, and does not focus on what goes on inside of the classroom. Some of the articles with a quantitative approach focus on what could be done in school(e.g., Zikl et al., 2015), but the majority focused on the outcomes of what actually goes on in school. Some of these articles used new or modified tests (e.g., Yılmazer & Masal, 2014), but in several articles, results and previously collected and verified data from PISA tests were reanalysed with a focus on parameters other than competences in mathematics, particularly which affective factors might influence mathematical literacy (e.g, Aksu & Güzeller, 2016; Ilbagi & Akgun, 2013; İş Güzel & Berbero⍰lu, 2010; Jürges et al., 2012; Koğar, 2015; Matteson, 2006; Papanastasiou & Ferdig, 2006).

In some articles, however, the researchers chose a qualitative approach. These articles used data from interviews with students who were asked to explain what they were thinking and doing (Chen & Chiu, 2016; Edo et al., 2013; Roth et al., 2015), or observation of teachers (Andrews, 2013; Höfer & Beckmann, 2009). A few qualitative studies considered more than one perspective (Andrews, Ryve, Hemmi, & Sayers, 2014; Dewantara, Zulkardi, & Darmawijoyo, 2015; Meaney, 2007; Tzohar-Rozen & Kramarski, 2013). They bring attention to what goes on in the classroom regarding mathematical literacy, and what might be done to teach mathematical literacy development. However, only a small proportion of the articles that met the parameters for this review actually focused on how teachers ought to work in the classroom to enable students to develop their mathematical literacy. Curricula, text-books and exams relate mathematical subjects to learning goal achievement, but they do not necessarily give attention to mathematical literacy (e.g, Gatabi et al., 2012; Jürges et al., 2012; Kunnskapsdepartementet, 2006; Ovayolu & Kutlu, 2011). However, PISA tests are especially focused on this subject (Allerup et al., 2006). Research might therefore ask whether students in several countries actually work with the issues on which they are tested through PISA.

Implications for primary and lower secondary school teaching

Students' development of mathematical literacy in school seems to be a complex process influenced by a large set of variables (Zhao et al., 2011). Altogether, the reviewed articles point to three sets of crucial factors regarding this: teacher style and priorities (Höfer & Beckmann, 2009; Kramarski & Mizrachi, 2006; Lin & Tai, 2015; Roth et al., 2015; Tai & Lin, 2015), affective qualities (Aksu & Güzeller, 2016; İş Güzel & Berbero⍰lu, 2010; Tzohar-Rozen & Kramarski, 2013), and students' perceptions of the classroom and school environment (Areepattamannil, 2014). Common among these factors is the teacher, and what the teacher does to enhance the emphasis on mathematical literacy in the classroom. The prioritizing of valid, practical and real-life related mathematics problems is highlighted

(Dewantara et al., 2015; Matteson, 2006; Yılmazer & Masal, 2014). This is important because considerable attention on students' conceptual understanding and procedural fluency alone, without systematic attempts to forge connections, does not provide recurrent opportunities for real-life problem-solving (Andrews, 2013). According to several researchers, problem-solving styles play an important role in mathematical literacy (Edo et al., 2013; Gatabi et al., 2012; Lin & Tai, 2015), and students who do not adopt an active problem-solving attitude do not develop mathematical literacy to the same extent as those who do (Tai & Lin, 2015). Furthermore, the classroom climate is negatively influenced by high anxiety and low confidence levels. According to İş Güzel and Berberoğlu (2010), both the interest and enjoyment of mathematics among students become negatively related to mathematical literacy when they experience that learning achievement and mathematical literacy are not the same. Scientific experiments make it possible to create situations in which formal knowledge and mathematical activities can be combined in understanding the subject matter (Höfer & Beckmann, 2009; Ovayolu & Kutlu, 2011). To support mathematical literacy, teachers need to devise a style of teaching that includes conventional and applied knowledge. As a consequence, Lin and Tai (2015) suggest that teachers must consider methods for explicitly teaching various learning strategies to improve students' mathematical literacy, including problem analysis and self-regulation development (Kramarski & Mizrachi, 2006; Tzohar-Rozen & Kramarski, 2013). This approach will rely on the presentation of real-life problems and open-ended interpretation problems (Dewantara et al., 2015; Ovayolu & Kutlu, 2011; Yılmazer & Masal, 2014), competence in reading and analysis of problems (Andrews et al., 2014), and the ability to approach problems from a critical perspective. Finally, students' perceptions of the classroom and school environment will be influenced by teaching priorities(İş Güzel & Berbero�lu, 2010). Students need to be allowed to discuss, to co-operate in the learning process, and to experience an open-minded and inclusive learning environment in which the learning process prevails. Within a mathematics classroom that does not acknowledge the effect of affective qualities such as self-efficacy, attitudes regarding mathematics, study discipline, anxiety, and interest (Aksu & Güzeller, 2016), the environment for students' development of mathematical literacy will suffer (Areepattamannil, 2014).

Discussion

According to the body of published research available for this review on mathematical literacy in schools, identifying what teachers and schools ought to do to enhance students' development of mathematical literacy seems to be almost as big a challenge as teaching for mathematical literacy itself. The concept of mathematical literacy is quite widely defined by the OECD (1999, 2003, 2009, 2012), and seems to be a political rather than a subject matter concept. Political concepts may be revised in accordance with changes in political needs and desires. Only to some extent did we find articles in this review that take a stand on the content of a mathematical literacy definition from a subject matter perspective (Andrews, 2013; Edo et al., 2013; Gatabi et al., 2012; Höfer & Beckmann, 2009; Meaney, 2007). The authors of these articles need to interpret the definition within the field of mathematics to narrow down the number of influential factors when conducting qualitative studies on the operationalization of the concept in schools. The lack of clarity around the concept makes it difficult for teachers to know what to do. Even though the definition of the concept changes from document to document (OECD, 1999, 2003, 2009, 2012), policy documents are quite clear on the expectations regarding the prioritization of mathematical literacy in schools. The nuanced yet continuous development of the concept makes teaching for mathematical literacy challenging because the continuous development of the definition stemming from political influence on the concept makes revised interpretations necessary. This makes it difficult for teachers to find help in the text-books they use in their teaching or in the prevailing curriculum.

Furthermore, researchers struggle in the attempt to establish a clear picture of teacher priorities needed to fulfil political expectations; therefore, there also does not seem to be much guidance for teachers in the research. Research on PISA test results seems to be aimed towards further explanations or the social consequences of results that have already been established. This is important knowledge about students' mathematical literacy development, but it does not help the teacher. We find it rather puzzling that the vast majority of the research articles on mathematical literacy in this review did not emphasize qualitative approaches to what goes on in the mathematical literacy-enhancing classroom. It seems that the research environment should give more priority to the introductory question of how to teach for mathematical literacy (Sfard, 2014). From this review, we have found some crucial points on this issue. First, it seems that teachers do not know what to prioritize, and that they do not get much help from the curriculum or text-books. Second, it seems that specific attempts to work directly with mathematical literacy through mathematics alone only influence students' mathematical literacy to a small extent. Third, it seems that teaching for mathematical literacy calls for something other than the traditional teaching of mathematics, in which individual task solving and a well-defined classroom structure prevail. This implies that changes should to be made to enable mathematics teachers to cope with these three challenges. A more holistic approach to the teaching of mathematics might offer students a fair chance of developing their mathematical literacy to some extent while they still are in primary or lower secondary school.

This review found that extensive attention was given to quantitative data regarding student performance on mathematical literacy-related problems. Further prioritizing such research would not be expected to address what could be done in the classroom to improve this issue. Teachers are uncertain about what to do, and specific attempts to work directly with mathematical literacy through mathematics alone have not been successful. Furthermore, it seems that teaching for mathematical literacy calls for something other than traditional mathematics teaching. Research-based answers to these challenges will help both teachers and the research community to pave the way for teaching priorities that will enhance mathematical literacy development. For such answers to be found, research on mathematical literacy in schools needs to change its perspective. In addition, more qualitative projects, such as classroom studies that focus on teachers' priorities regarding mathematical literacy and studies of best-practice, or research-based interventions in which teachers and researchers co-operate, are also needed.

Conclusions and implications for future research on mathematical literacy

The present review revealed that research in the field of mathematical literacy in schools faces a number of complex challenges. The rather nuanced and continuously developing definition of the mathematical literacy concept makes it somewhat difficult for teachers and the research community to decide how to teach for mathematical literacy, and subsequently makes it challenging for teachers to gain valid and reliable guidance.

The aim of future research on mathematical literacy should be to fulfil Sfard's (2014, p. 141) request for theoretical and empirical studies regarding how to teach for mathematical literacy. The approach to such a quest seems to be through increased emphasis on qualitative research, for instance, through studies of best-practice and research projects involving practising teachers. Therefore, the research community's attention needs to shift from nurturing data and findings that highlight student results on mathematical literacy tests to research on what to do in order to improve the students' opportunities to develop mathematical literacy. A starting point for such a shift in focus could be to examine how mathematical literacy is understood, facilitated and experienced in schools.

Acknowledgements

We would like to acknowledge the librarians at Sogn og Fjordane University College for their assistance in providing us with the literature used in the preparation of this review article.

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Appendix1

Details of publications reviewed (N= 28)

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
Aksu&OktayGüzeller (2016)	Attempt to classify successful and unsuccessful students in terms of mathematical literacy according to interest in the course, attitude, motivation, perception, self-efficacy, anxiety and study discipline variables, and to determine the effect of these variables on classification.	N=1391 15-year-old students from Turkey	Quantitative data from PISA 2012 CHAID analysis (decision-tree technique), SPSS and WEKA software	Affective qualities such as self-efficacy, attitude, study discipline, anxiety and interest should be developed to ensure higher positioning for Turkey in large tests like PISA. This calls for changes in the curriculum and changes that consider the affective qualities instead of focusing on merely cognitive qualities in course programs. More emphasis should be placed on the self-efficacy perception, course attitude and anxiety for the Turkey	Complete similar studies involving other countries, and future collections of PISA data from the Turkey sample. It is also recommended that the classification results with respect to mathematical literacy should be retested with different analysis methods.

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
				sample for mathematical literacy.	
Andrews (2013)	How teachers conceptualize and present mathematics to students framed against the five strands of mathematical proficiencyof Kilpatrick et al. (2001): - Conceptual understanding - Procedural fluency - Strategic competence - Adaptive reasoning - Productive disposition	N=4 teachers in Finnish comprehensive schools	Qualitative research Video-based case-study of 4–5 successive lessons	Considerable attention is focused on students' conceptual understanding and procedural fluency, but there is an absence of any systematic attempt to forge connections. Few opportunities for real life problem-solving.	Explore the reason for Finnish students' repeated PISA success, perhaps byexamining factors external to individual classrooms.
Andrews, Ryve, Hemmi & Sayers (2014)	The resonance between classroom practice and the mathematical literacy component of the PISA assessment	Twenty mathematics teachers (four each from England, Finland, Belgium, Hungary and Spain) A few teacher	Qualitative study Two unrelated data sets: Data set 1: Video study of mathematics teaching	In Finland, it seems that it is more common to involve parents in homework tasks. It is possible that Finns	Is the mathematics education research community overestimating the influence of classroom interaction on student learning?

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
	framework.	educators in Finland (two small groups) and Sweden (individual)	undertaken in England, Finland, Flanders, Hungary and Spain (focused on how four teachers in each country, selected against local criteria of quality, typically present mathematics to their students), and translated transcripts (into English). Dataset 2: Interview and focus-group interviews (two) with Swedish and Finnish teacher educators, respectively	excel on language-based tests of mathematical competence such as PISA not because they are particularly mathematically competent—their TIMSS score suggest they are not—but because they are highly competent readers.	
Areepattamannil (2014)	Factors related to adolescents' reading, mathematics and science literacy	N=4826 15-year-old students from India	Quantitative study PISA 2009 test results	The study underlines the relationship between gender, metacognitive learning strategies and	Research to better understand student and schoollevel predictors that can be found to be related and unrelated to academic

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
				students' positive perceptions of the classroom and school environment to academic performance.	performance.
Chen & Chiu (2016)	Examine the impact of use of computer-based collaboration scripts on primary school students' metacognitive self-regulation and mathematical literacy	N=80 fifth-grade students from Taiwan	Quasi-experimental study In groups, students carried out a design project using tessellation on computers in three sequential phases, with a plenary session after each phase to sharethe products with the other students. The students answered a questionnaire after each phase to provide data on metacognitive self-regulation. Mathematics test	Working with support of collaboration scripts positively impacts metacognitive self-regulation in the controlling aspect of the script and mathematics achievement. No registration of impact on mathematical literacy achievement.	Similar studies with older students are needed, as is a comparison between the use of computerized scripts in face-to-face and computer-mediated collaborative learning and those given by a live teacher. Further studies are needed on students' metacognition and academic achievement.

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
			developed to measure students' mathematical literacy achievement in the literacy area "space and shape" with an emphasis on plane geometry. Quantitative analysis		
Dewantara, Zulkardi&Darmawijoyo (2015)	The activation of fundamental mathematical capabilities that underpin the process of mathematical literacy. The potential effects of a set of PISA-like problems in developing students' mathematical literacy.	N=28 seventh-grade students from Indonesia	Qualitative research Students' test results and interviews	Valid and practical PISA-like mathematics problems (developed in this study) have the potential to develop students' mathematical literacy.	
Edo, Hartono &Putri (2013)	Secondary school students' difficulties in modelling	N=73 ninth-grade students from Indonesia	Qualitative study Modelling tests and interviews	Students find it difficult to model situations mathematica	

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
	problems from the PISA-model at levels 5 and 6			lly in problems and to evaluate the reasonableness of a mathematical solution in the context of real-world problems. Students have no problem in solving mathematical problems they have constructed.	
Gatabi, Stacey &Gooya (2012)	Comparison of Iranian and Australian mathematics text-books Text-book problems that show characteristics promoting mathematical literacy	Literature study Ninth-grade text-books	Qualitative research Content analysis	Text-books should include: - Problems with a variety of contexts (real life and scientific) - Problems without repetition of formulation, but requiring more formulation by students - Problems that are close to problem-solving - Mathematic	Framework for identifying how text-books are likely to promote mathematical literacy.

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
				al modelling is the key process of mathematical literacy	
Höfer& Beckmann (2009)	Integrating science into mathematics education to promote functional thinking and mathematical literacy	N=300 Two lessons in a German secondary school, 14–17-year-old students	Qualitative study Observation (audio and video analysis) of teaching sequences	To support mathematical literacy, teachers should devise a style of teaching that includes conventional and applied knowledge. Scientific experiments make it possible to create situations where formal knowledge and mathematical activities can be combined in understanding the subject matter.	More careful studies of students' abilities by testing them in new situations, and then again after a few weeks
Ilbagi&Akgun (2013)	Investigation of students' mathematical literacy in terms of PISA mathematical literacy questions	N=1227 15-year-old students from Turkey	Quantitative study Survey model. Analysis of students' responses to a nine-question test	High school science students show the highest performance in mathematical literacy, while	Reasons for the differences in results among different types of high schools

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
			(PISA 2003).	general high school students and vocational high school students show the lowest.	
Is Güzel&Berberoglu (2010)	Investigation of affective variables that are related to the mathematical literacy skills of 15-year-old Turkish students in PISA 2003	N=4855 15-year-old students from Turkey	Quantitative study on the PISA 2003 dataset for Turkish students Statistical analysis	The classroom climate is negatively influenced by high anxiety and low confidence levels among the students. The interest and enjoyment of mathematics among students was negatively related to mathematical literacy. This might be because learning achievement and mathematical literacy are not measured in the same way.	There is a need for closer investigation of students' attitudinal characteristics related to school mathematics and mathematical literacy, and their impact on cognitive measures.
Jürges, Schneider, Senkbeil&Carstensen (2012)	The effect of central exit exams in mathematic	N=4928 ninth- and tenth-grade students(acade	Quantitative study Longitudina	Central exit exams are significantly related to	

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
	s, students' mathematics performance and students' attitudes toward mathematics	mic and non-academic students) from Germany	l study Data from PISA-I study, mathematical literacy test and curricular knowledge test Retested one year later	better curricular knowledge, but have no significant effect on mathematical literacy.	
Ko�ar (2015)	Identification of the direct and indirect factors affecting the PISA 2012 mathematical literacy	N=4848 15-year-old students from Turkey	Quantitative analysis of the Turkey sample of PISA 2012 (relational screening model, multiple regression analysis)	The gender, economic, social and cultural status index and time allocated for learning mathematics independent variables have a significant influence on mathematical literacy.	The effect of more student activity in classes, more teaching of concepts, perseverance regarding difficult problems and more emphasis on problem-solving on mathematical literacy.
Kramarski& Mizrachi (2006)	The effects of online discussion embedded with metacognitive guidance on mathematical literacy and self-regulated learning. Problem-solving	N=86 seventh-grade students from Israel	Quantitative study Problem-solving tasks Pretest, posttest, real-life test Comparison group	Students exposed to online discussion and metacognitive guidance attained a higher level of mathematical literacy and self-regulated learning than those	The need to understand more about how productive discussion emerges in online communication, and the need for researchers to continue to define and examine features of communications that are linked

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
				exposed to face-to-face discussion, with or without metacognitive guidance. Instructional methods on mathematical literacy are vital for increasing the result.	to qualities of mutual engagement, quality of joint work, and individual learning.
Lin & Tai (2015)	How various mathematical learning strategies affect the mathematical literacy of students	N=192,819 15-year-old students from Taiwan	Quantitative study Latent class analysis of PISA 2012 results	Various learning strategies improve students' mathematical literacy. Teachers must consider methods for explicit teaching of these strategies in the classroom.	Further research on the relationship between learning strategies and mathematical literacy
Matteson (2006)	The frequency and categories of external representations used to present and solve assessment items	Third- to eighth-grade students fromthe United States	Quantitative study Analysis of the 2003 and 2004 Texas Assessment of Knowledge and Skills results(students solving algebra problems)	Representations are important to the development of mathematical literacy. By limiting the type and number of representations, students are not given the	Effectively developing mathematical reading comprehension skills, the role of reading in developing problem-solving strategies and skills. What connections exist between mathematical literacy and

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
				flexibility or opportunity to create representational constructs or to explain their mathematical thinking, which makes it difficult to assess their level of mathematical literacy.	reading comprehension?
Meaney (2007)	How judgements concerning mathematical literacy are affected by differences in problem context	N=71 fourth- and eighth-grade students from New Zealand	Qualitative study Teachers administer tasks at school. Videotaped one-to-one interviews in which teachers followed a script and students had to explain how they would solve the tasks.	Students' mathematical thinking can be linked to their levels of mathematical literacy. Context and demands of the task influence the level of mathematical literacy needed.	The relationship between language and mathematical literacy. Can providing students with specific instructions about how to structure mathematical arguments support their mathematical thinking?
Ovayolu&Kutlu (2011)	Cognitive dimensions of reproduction, connection and reflection that constitute the	N=4942 15-year-old students from Turkey	Quantitative study Analysis of PISA 2006 mathematics sub-test results	For implementation of comprehension strategies, the scope and the content of the curriculum should be	Comparative studies of PISA 2006 and 2009 results Comparative studies between Turkey and other countries

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
	students' mathematical thinking processes			based on real-life situations. Practical use of tools and materials should be emphasized, as well as out-of-school activities. There should be less focus on sole problem-solving activities.	
Papanastasiou&Ferdig (2006)	Relationship between computer use and mathematical literacy	N=2135 15-year-old students from the United States	Quantitative study PISA test analysis	"Passive" or mechanical use of computers alone does not highly correlate with increased academic growth. Some ways of using computers were associated with higher levels of mathematical literacy (e.g., electronic communication, for writing	More experimental type research on mathematical literacy acquisition and its relationship to technology use.

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
				papers). Other activities (e.g., programming and using drawing-type software) were associated with lower levels of mathematical literacy.	
Roth, Ercikan, Simon &Fola (2015)	To investigate possible linguistic bias in PISA items differentially solved by students from different language groups	N=33 students (mean age: 15.6 years) from Canada	Mixed-method approach (multi-level-analysis of PISA mathematics items, and think-aloud-interview sessions while solving the selected PISA mathematics items)	Think-aloud situations offer students the opportunity to express themselves much more than in one-sentence responses in paper-and-pencil format. Conceptual understanding of what is at stake is crucial.	Does PISA actually assess conceptual understanding and mathematical literacy, or: a) Are students' answers sometimes based on being familiar with the background (e.g., skateboarding) or knowledge of specific (technical) words? b) Does

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
					the grammatical structure create ambiguity or inhibit comprehension?
Ryan (2013)	Why has Australian school student achievement in reading and mathematical literacy fallen in the PISA collection since 2000?	15-year-old students from Australia: In PISA 2003: N=12,551 In PISA 2006: N=14,170 In PISA 2009: N=14,251	Quantitative analysis of Australian PISA studies from 2003, 2006 and 2009	The decline in mathematical literacy was more pronounced at the top of the distribution of students (PISA 2009 compared with PISA 2003).	
Tai & Lin (2015)	The relationship between problem-solving styles and mathematical literacy	N=193,370 15-year-old students from Taiwan	Quantitative study Latent class analysis of PISA 2012 results	Problem-solving styles play an important role in mathematical literacy. Students who do not adopt an active problem-solving attitude have poorer mathematical literacy than those who do.	Investigating differences in problem-solving skills between students in ninth and tenthgrade, and between boys and girls.
Tzohar-Rozen&Kramarski	The effect of an affective	Fifth-grade students from	Mixed methods	The study shows that	It is proposed that:

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
(2013)	self-regulation programme on emotions, performance in solving mathematical literacy tasks and long-term reflection on the programme	Israel: N=107 consisting of 54 students in an affective self-regulation group, and 53 students in a control group.	Intervention program, pre- and posttest Factor analysis and interviews	the affective self-regulation program increases mathematical literacy. The study also widens the knowledge of the emotional component of self-regulation learning.	- The effectiveness of this intervention should be examined in a variety of learning environments, such as in co-operative learning and in fading conditions. - Longitudinal studies would also be useful to determine the impact. - A comprehensive examination of interventions for different types of learner (boys and girls), students with different achievement levels, students with learning disabilities and student with math anxiety.
Van Hoof, Janssen, Verschaffel& Van Dooren (2015)	Attempt to develop a test instrument that allows the assessment of density, operations and size to be	N=213 fourth-grade students from nine schools in Belgium	Quantitative analysis of a paper-and-pencil test	A good understanding of size is a prerequisite for gaining understanding regarding operations. This means that more	

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
	combined in an integrated manner			attention should be paid to enhancing pupils' understanding of the size of rational numbers in the classroom.	
Van Hoof, Vandewalle, Verschaffel& Van Dooren (2014)	Rational numbers are an essential part of mathematical literacy, but cause a lot of difficulties for students because of a natural number bias (inappropriate use of natural number properties when learning about rational numbers).	Study 1: N=291 eighth-grade students and an additional N=10 eighth-grade students Study 2: N=301 tenth-grade students andN= 305 twelfth-grade students Both studies from Belgium	Quantitative and qualitative two-cycled study. Study 1 contained a written test for all eighth-grade students, followed by interviews with 10 eighth-grade students who solved similar tasks individually. Study 2 contained the same written test for all tenth- and twelfth-grade students.	Students tend to doubt the applicability of their natural number knowledge in addition and subtraction items more than in multiplication and division items.	
Yilmazer&Masal (2014)	Relationship between seventh-grade students' arithmetic performanc	N=297 seventh-grade students from Turkey	Quantitative study Statistical analysis	To increase mathematical literacy, primary school students should be	

Reference	**Focus of attention**	**Setting (informants, type of school, number of participants)**	**Method, data sources**	**Implications for teaching for mathematical literacy**	**Recommendations for further research on mathematical literacy**
	e and mathematical literacy			presented with real-life problems and open-ended interpretation problems, and be enabled to approach problems with a critical perspective. In addition, qualified primary school teachers who are engaged in mathematics should be fostered.	
Zhao, Valcke, Desoete, Verhaeghe&Xu (2011)	Prediction of mathematics performance in primary school	N=10,959 primary school students (first- to sixth-grade) in China	Quantitative study Data collected through written mathematics tests on student level, adjusted to grade level. Multilevel approach for analysis – school level, class level, student level.	The acquisition of mathematical literacy in primary school is a complex process influenced by a large set of variables.	Attention may be paid to additional variables at the school and class level: school leadership, didactical approaches, handbooks used, etc. Alternative research designs such as video-based analysis should be applied to study teacher quality, student engagement, teacher and student beliefs,

Reference	Focus of attention	Setting (informants, type of school, number of participants)	Method, data sources	Implications for teaching for mathematical literacy	Recommendations for further research on mathematical literacy
					etc.
Zikl, Havlíčkóvá, Holoubková, Hrníčková&Volfová (2015)	Comparison levels of mathematical literacy of pupils with mild intellectual disabilities and intact pupils	N=48 fourth-grade students from the Czech Republic	Quantitative study Modified and adjusted TIMSS tasks according to curricular categories: - Numbers - Geometrical shapes - Measurements	Enough time to practice or take extra lessons. It is also necessary to reduce schoolwork, use appropriate teaching methods, and individualize work for students with mild intellectual disabilities. Despite such measures,one must reckon a significant difference in the levels of mathematical literacy.	