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Realistic Mathematics Education in Digital Era Elementary Schools: A Systematic Literature Review

Prabandari Listyaningrum [a,*], Heri Retnawati [a], Harun [a], Hamidulloh Ibda [b]

[a] *Department of Doctor of Basic Education, Faculty of Education and Psychology, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia*
[b] *Department of Madrasah Ibtidaiyah Teacher Education, Faculty of Tarbiyah and Teacher Training, Institut Islam Nahdlatul Ulama Temanggung, Temanggung, Indonesia*

*Corresponding author: *prabandarilistyaningrum.2021@student.uny.ac.id*

***Abstract*— Several studies explore realistic mathematics education (RME) in digital-era elementary schools, but studies with SLR are minimal. This article presents SLR on RME in digital-era elementary schools from 2022 to 2024. This research method is SLR and PRISMA assisted by the Publish or Perish 8 application, VOSviewer version 1.6.20, Mendeley version 1.19.8, and ATLAS.ti version 7.5.16. The findings of 757 Scopus articles were filtered to 33 and analyzed with ATLAS.ti, and the results were presented according to the research questions. The study findings revealed that RME is a mathematics learning approach from Freudenthal's learning theory, which, since 2016, has developed as a "new math" approach to bring students closer to mathematics, directing students to become inventors and researchers. RME is applied with digital mathematical tools, Hypothetical Learning Trajectory (HLT) games, virtual Lesson Study for Learning Community (LSLC), primary school geometry learning, curriculum, media, numerical, computational, translation, reflection, realistic word problems, mathematical beliefs, applications, scientific reporting, and Realistic Mathematics Engineering (RMEng). Indonesia, Malaysia, and Australia are the countries that implement digital integrated RME. RME learning with ICT improves higher-order thinking skills in geometry, beam trajectory, student ability in the ellipse, mathematical competence of slow learner students, mathematical literacy, exploration, collaboration, STEM projects, problem-solving skills in grades 1-3, data concepts in grade 4, data presentation in grade 5, and data processing in grade 6. According to current developments, future research needs to explore the theme of realistic mathematics education in the digital era of elementary schools.**

***Keywords*—Realistic mathematics education; digital era; elementary schools; mathematics learning.**

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I. INTRODUCTION

Several researchers have studied realistic mathematics education (RME) in digital-era elementary schools from 2021-2024. These studies include the RME approach in elementary school mathematics learning to improve problem-solving skills [1], mathematical reasoning and communication in rural areas with RME [2], the application of RME at the tertiary level in an inverted classroom [3], the application of RME with the Treffinger learning model to improve math learning outcomes and creative thinking skills [4], RME learning with ethnomathematics in the material of cylinder volume and surface area assisted by GeoGebra [5], RME for student problem solving [6], RME to improve competence in linking mathematics to life in students [7], RME for problem-solving for students with disabilities [8], and RME through digital puzzle games for children [9]These findings show that research on RME still needs to be improved in elementary schools in the digital era, so it is required.

Research on RME in elementary schools in the digital era with systematic literature review (SLR) and allied there are several findings in 2022-2024. Research related to the theme is SLR on RME to improve students' mathematical thinking skills [10], artificial intelligence in mathematics learning with SLR [11], bibliometric review on RME in Scopus from 1972-2019 [12], meta-analysis study on RME in the last two decades [13], SLR study related to augmented reality in mathematics education [14], SLR study on linear programming learning activities [15], SLR study on augmented reality in STEM education [16], and SLR on the proportions of RME and PMRI [17]. The findings of this research with SLR have yet to find SLR on RME in digital era elementary schools.

RME becomes a model or approach to learning mathematics in elementary schools in the digital era. It is more contextual and relevant for students, allowing them to relate mathematical concepts to real-world situations [18]. In the era of digital technology integrated into every aspect of education, RME offers a relevant strategy to incorporate technology in mathematics learning [19]. This approach encourages students to face real challenges they may encounter daily while using digital tools to support problem-solving, understanding mathematical concepts, and critical thinking [20]. Besides integrating technology in RME, this approach is about more than just using digital tools. Still, RME emphasizes student-centered learning experiences, allowing them to play an active role in their learning process [21], [22]. Therefore, teachers should be critical in guiding and supporting students in exploring mathematical concepts using the RME approach in the digital era.

Conceptually, RME is referred to in some literature as a learning model and learning approach. Research mentioned that RME is a mathematics learning approach that is applied by referring to the use of contexts that students have done, collaboration with peers, and dialog processes, and boils down to the ability of students to solve their problems in groups or personally [23]. According to Hans Freudenthal (1905-1990) [24], [25], RME as a model or approach has a syntax of finding contextual problems, problem-solving, and organizing teaching materials [26], [27]. In detail, RME develops various procedures integrated with models, methods, strategies, and media for learning mathematics in elementary schools according to the needs of students and contexts [28], [29]In the context of this research, RME is limited to being applied in digital-era elementary mathematics learning. The study focuses on highlighting the current literature to reveal the concept, learning, and impact of using RME in digital-era elementary mathematics learning.

Unique contributions show how this research provides something new or significant to existing fields of study, such as the application of digital technology in realistic mathematics education with the application of applications, AI, games, and online learning platforms that strengthen RME in elementary schools [30], [31]. Another contribution is strengthening teachers' digital competence in preparing, planning, implementing, and evaluating all digital devices as a tool for implementing RME in elementary schools [32]. Research gaps are areas in literature that are unexplored or have received insufficient attention. First, there is a lack of technology implementation in realistic mathematics education in elementary schools. Although RME is already used in some elementary schools, research on how technology can be applied effectively to support this approach may be limited [33]. Second, the lack of empirical research in elementary schools with SLR is of interest. Most research may focus on schools in developed countries and be carried out empirically, so there is an opportunity to explore how technology-based realistic mathematics education is implemented in elementary schools with SLR techniques, which may have different challenges and opportunities [34]. Third, there is a lack of focus on teacher digital competence. There is a gap in research regarding the digital competence of teachers in implementing technology-supported RME approaches in the digital era, especially in elementary schools [35], [36]. By emphasizing these unique contributions and gaps in the introduction, the scientific article will appear relevant, have a clear research direction, and make a new contribution to the existing literature.

The study of RME in digital-era elementary schools is essential because it will explore further how the concept of learning and its impact on elementary school mathematics learning can positively contribute to improving the quality of learning and student engagement. Based on the background, research on RME in digital era elementary schools is urgent to map the concept, learning, and impact that will be a reference for teachers in learning elementary mathematics. To answer the problem, the researcher asked three research questions: (i) How is the concept of RME in digital era elementary schools? (ii) How is RME learning in digital-era elementary schools? and (iii) How is RME impacting digital-era elementary schools?

II. Materials and Methods

A. Research Design

This research was designed using the systematic literature review (SLR) method through the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) technique: identification, screening, eligibility testing, data inclusion, analysis, and presentation of findings referring to research questions [37] which is analyzed comprehensively [38]. This SLR research identified articles published in 2022-2024 indexed by Scopus to map the concept, learning, and impact of RME in digital-era elementary schools. The findings and analysis of this systematic literature review were designed using a structured PRISMA technique to find complete data on the concept, learning, and impact of RME in digital-era elementary schools.

B. Inclusion and Exclusion Criteria for Selection of Publications

This stage determined nine steps/indicators obtain quality literature according to the research question, namely (1) scientific articles indexed by the Scopus database; (2) scientific articles are only peer-reviewed, while theses, theses, dissertations, policy briefs, research reports, book chapters, papers, conference proceedings, and books are not used; (3) scientific articles published in 2022-2024; (4) scientific articles in English; (5) articles searched through Publish or Perish 8; (6) scientific articles searched according to the main topic of RME in digital era elementary schools; (7) scientific articles that are full PDF; (8) scientific articles published in open access journals; (9) scientific articles not selected from Google Scholar indexers and other trivial databases.

C. Screening and Eligibility Assessment for Data Analysis

Article screening uses the technique of writing a specific "tit-abs-key" according to the topic of RME in digital era elementary schools on February 29, 2024, which is detailed into keywords to get abundant articles. Based on searching and filtering through Publish or Perish 8, 757 Scopus-indexed articles were found with details in Table 1. The findings of the 757 articles were that the same articles were discarded, and 40 were selected. The 40 selected articles were entered the Mendeley Desktop application version 1.19.8 to find the initial network map.

TABLE I
ARTICLE FINDINGS THROUGH PUBLISH OR PERISH 8 PUBLICATIONS 2022-2024.

No.	Keyword	Quantity
1	Realistic mathematics	200 articles
2	Realistic mathematics learning	133 articles
3	Realistic mathematics education	136 articles
4	Realistic mathematics education (RME)	54 articles
5	Concept of Realistic Mathematics Education	32 articles
6	Realistic mathematics education learning	91 articles
7	Impact of Realistic Mathematics Education	15 articles
8	Realistic Mathematics Education in Digital Era	1 article
9	Realistic mathematics education in elementary school	8 articles
10	Realistic mathematics education in primary school	12 articles
11	Realistic mathematics education in school	57 articles
12	Realistic mathematics education in basic school	3 articles
12	Realistic mathematics education in basic education	5 articles
13	Realistic Mathematics Education for Children	10 articles
	Quantity	757 articles

Furthermore, the file was saved in RIS format to be entered into the VOSviewer version 1.6.20 application to get the results of the initial thematic association analysis on the theme of RME in digital era elementary schools referring to which illustrates a very complex association pattern in Figure 1, and visualization of article distribution based on keywords in VOSviewer in Figure 2 below.

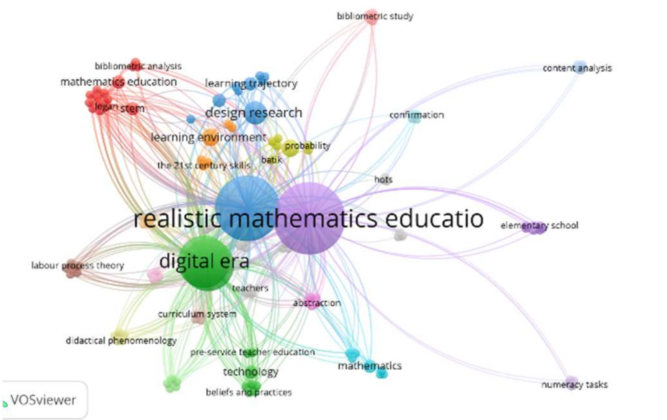

Fig. 1 Initial network visualization in VOSviewer

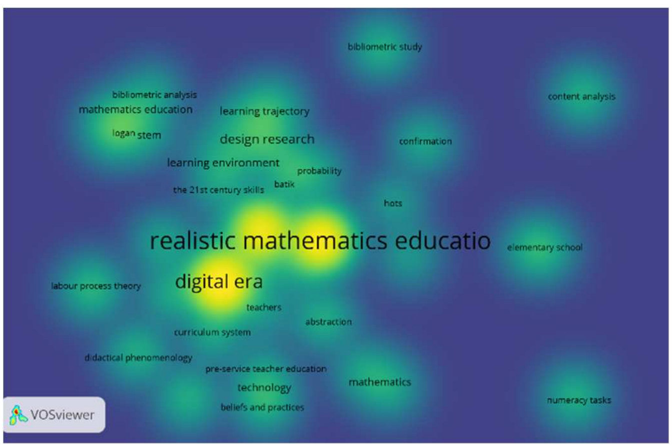

Fig. 2 Visualization of article distribution based on keywords

Fig. 1 and Fig. 2 show that the study of RME in digital era elementary schools is very close to several other study themes such as RME, digital era, curriculum system, 21st-century skills, learning environment, design research, local instructional theory, constructivist approach, geometry, abstraction, mathematical competencies, critical thinking skills, batik, and HOTS. Some keywords far from the study's central theme are *numeracy tasks, beliefs and practices, content analysis, didactical phenomenology, labor process theory, confirmation, bibliometric study, bibliometric analysis, stem, mathematics education,* and *learning trajectory*. From the visualization above, 131 keywords were obtained, with the most distribution being realistic mathematic education 33 keywords, RME 28 keywords; digital era 19 keywords; elementary schools 19 keywords; design research 5 keywords, STEM 2 keywords; mathematics education 2 keywords, learning environment 3 keywords, local instructional theory 3 keywords, while the rest are 1 keyword. This shows that the themes of RME, the digital era, and elementary school are interesting to study because there are the most keyword findings from 131 keywords in 33 articles.

D. *PRISMA Flow Diagram*

The PRIMA technique is applied in article searches through four stages: identification, screening, eligibility, and inclusion [39]. Each stage is carried out using the help of the Publish or Perish 8 application, VOSviewer version 1.6.20, and Mendeley Desktop version 1.19.8. The search stages with the PRISMA flowchart are described in Fig. 3 below.

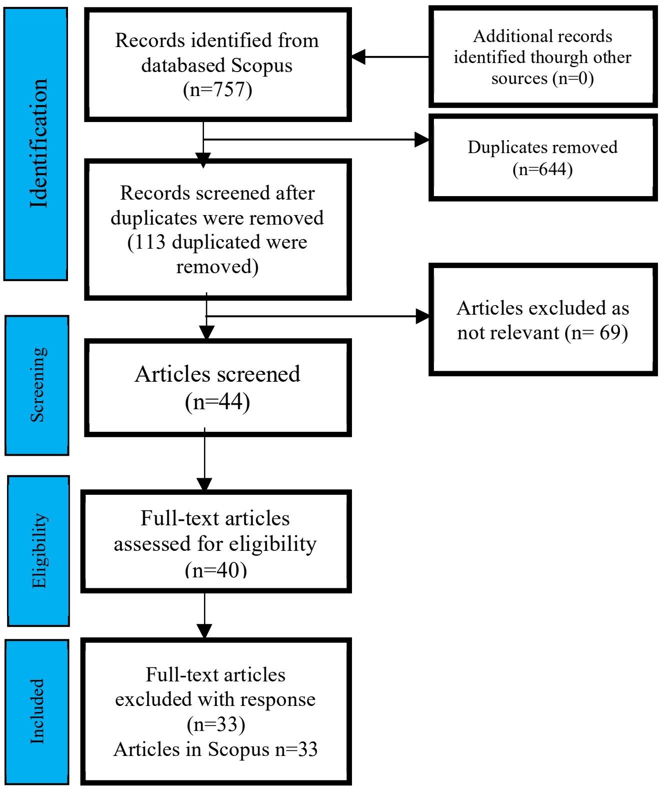

Fig. 3 PRISMA Flow Diagram for Systematic Review [40]

At the identification stage, through the Publish or Perish 8 application, 757 Scopus-indexed articles were found (see Table 1). In the screening stage, there were 644 similar articles referring to keywords, and the remaining 113. The screening stage is done by determining similarities that do not refer to the database because the SLR technique here only selects the Scopus database, choosing similarities in terms of the selected keywords. At the screening stage, 44 articles were obtained, and 69 irrelevant literatures were discarded. The eligibility stage received 40 selected articles that were full-text chosen to be read, reviewed, and analyzed, while 7 articles were discarded. The included stage obtained 33 selected articles in terms of tit-abs-key, and the substance of the literature refers to the research question. Next, the 33 full PDF articles were entered into the ATLAS.ti version 7.5.16 application for analysis and result grading. The coding stages in ATLAS.ti are by preparing 33 full PDF articles, opening the application, opening the document menu, new-add document, reading per article and adjusting according to research questions by clicking create free quotation with categories according to research questions, and then sentences relevant to the category are blocked, clicking coding-enter code name(s) and entering the coding name of the concept, learning, and impact of RME. The next step was to read and code all the articles according to the research questions. After that, to save, click the codes-output-all codes with quotations menu, then the results appear, and click the file, which is held in doc/word form and then presented according to the research questions.

III. Results and Discussion

After the coding process in the ATLAS.ti application was completed, and before presenting the results of the analysis of selected articles, the 33 found articles were first presented. In Table 2, the findings of 33 articles are presented with journal criteria (journal name, volume, edition, and year of publication) and citation, country of research, methodology, and research question (RQ), namely RQ A. RME concept in digital era elementary schools; B. RME learning in the digital era of elementary schools; C. The impact of RME in the digital era of elementary schools is in Table 2 below.

TABLE II
Finding 33 articles from the Scopus application Publish or Perish 8

No	Journals	Countries	Method	RQ
1	Journal on Mathematics Education, 13 No. 1 2022 [41]	Indonesia	Experiment	C
2	Journal on Mathematics Education, 13 No. 2 2022 [42]	Indonesia	Validation study	B
3	European Journal of Educational Research, 11 (1) 2022 [43]	Vietnam	Experiment	C
4	Cogent Education, 9, 1 2022 [44]	Several countries	Bibliometric analysis	B
5	Journal on Mathematics Education, 13 No. 3 2022 [45]	Indonesia	Developmental research	B
6	Journal on Mathematics Education Volume, 13 No. 4 2022 [46]	Indonesia	Development of the learning design	A
7	Mathematics Teaching Research Journal, Vol 15 No 4 2023 [47]	Turkey	Mixed Methods	A
8	Journal on Mathematics Education, 14, No. 1 2023 [48]	Vietnam	Investigative Research	A
9	Infinity Journal 12 (1) 2023 [49]	Indonesia	R&D (ADDIE)	C
10	Mathematics Teaching Research Journal, Vol 15 No 5 2023 [50]	Indonesia	R&D (Borg and Gall)	C
11	European Journal of Educational Research 12, 1 2023 [51]	Vietnam	Quantitative research	B
12	International Journal of Educational Management and Development Studies, 4, 2 2023 [6]	Philippines	Pre-experimental	A
13	European Journal of Educational Research, 11, 1 2023 [52]	Indonesia	R&D (Tjeerd Plomp)	C
14	Journal on Mathematics Education, 14, No. 1 2023 [53]	Thailand	Qualitative	A
15	Journal on Mathematics Education, 14, No. 2 2023 [54]	Indonesia	Design research Kirkpatrick model	C
16	Journal on Mathematics Education, 14, No. 3 2023 [55]	Indonesia	Design research type validation	B
17	Journal on Mathematics Education, 14, No. 4 2023 [56]	Indonesia	Descriptive qualitative	C
18	Journal on Mathematics Education, 14, No. 4 2023 [57]	Indonesia	Development study	B
19	Applied Mathematics & Information Sciences, 17 1 2023 [58]	Saudi Arabia	Quasi-experimental design	A
20	Front. Educ., 8, 2023 [59]	Several countries	Scoping review	B
21	International Journal of Science and Mathematics Education 2023 [60]	Spain	Naturalistic study	B
22	Pedagogika, 150, 2 2023 [61]	Indonesia	Cross-sectional	B
23	International Journal of Human-Computer Interaction 2023 [62]	Turkey	Qualitative	C
24	Journal on Mathematics Education 15, No. 1 2024 [63]	Indonesia	Investigative Researching	B
25	Journal on Mathematics Education 15, No. 1, 2024 [64]	Indonesia	R&D	B
26	BMC Medical Education 24: 36 2024 [65]	China	Questionnaire	B
27	Journal für Mathematik-Didaktik 45, 2, 2024 [66]	USA	Descriptive	C
28	Education and Information Technologies 2024 [67]	Ethiopia	Quasi-experimental	C
29	Research in Mathematics Education 2024 [68]	Greece	Comparative evaluation study	C
30	Journal on Mathematics Education 15, No. 1, 2024 [69]	Indonesia	Development with Local Instructional Theory (LIT)	B
31	Cogent Education 11, 1, 2024 [70]	Canada	Mixed methods	C
32	Journal of Critical Realism, 23, 1 2024 [71]	Norway	Mixed methods case study	A
33	Educational Studies in Mathematics, 115 2024 [72]	China and Germany	Quantitative research	B

A. RME Concepts in the Digital Era of Elementary Schools

The findings of the article state that RME is a mathematics learning approach that departs from the learning theory developed by Hans Freudenthal in the Netherlands in 1983 to prepare students to be close to mathematical concepts and direct them to become inventors and researchers [58]. Freudenthal's theory sees mathematics as a human activity [47], the activity of finding problems, organizing the subject of study, and solving problems in a realistic context [46], which has three heuristic principles, namely directed rediscovery, didactic phenomenology, and self-developed models [6]. RME is a pedagogical approach to mathematics learning that has developed rapidly since 2016 as a form of "new mathematics" reform. It is considered paradoxical to conventional mathematics learning, which focuses on textbooks and old theories [48]. RME is a mathematics learning approach with several stages, namely context-based learning, active learning, development of mathematical reasoning, concentration on processes and concepts, relationships between mathematical concepts, and emphasis on the constructive nature of mathematics [53], which is very much determined by new paradigms such as curriculum-integrated RME, literacy, learning techniques to catch up with the quality of numeracy and the Program for International Student Assessment (PISA) [71].

B. RME Learning in the Digital era Elementary schools

RME learning in the digital era is implemented with digital mathematical tools that require teachers' professional pedagogical skills [72], with games using Hypothetical Learning Trajectory (HLT) for children [42], which can be considered in virtual or digital learning [60]. Indonesia, Malaysia, and Australia are the countries that apply the most RME learning integrated with digital technology through computers and ICT in the classroom and individual learning [44], which is implemented in a mathematics learning environment through Lesson Study for Learning Communities (LSLC) with RME [45]. RME is applied to geometry learning by practicing batik with digital manipulative patterns using the CorelDraw application with flower patterns, clouds, and four small circles at the ends of flower petals [69]. RME is included in the curriculum, media, and in learning for numerical and computational skills from early to fifth-grade elementary school [51], translation and reflection of mathematics through dance [55], technology-based learning, engineering, mathematics [57], learning geometry in elementary schools [59], learning realistic word problems and elementary school mathematics beliefs [61], training, application, and scientific reasoning [63]. RME integrates natural sciences, health, pharmacy, medicine, online laboratories, and medical mathematics materials [65]. RME has developed into Realistic Mathematics Engineering (RMEng), integrating the RME approach with engineering design process procedures in mathematics learning in elementary schools [64].

Referring to the findings above, educators can implement several practical strategies to enhance teachers' digital competence in Realistic Mathematics Education (RME) learning in elementary school classrooms through training and professional development. Research highlights the importance of conducting Digital Tools Workshops for using digital mathematics tools such as GeoGebra, CorelDraw, and other teaching applications compatible with RME [32], [73]. Additionally, developing Hypothetical Learning Trajectories (HLT) based on interactive educational games is essential to boost elementary students' engagement in RME learning [74] [75]. Technically, teachers should be encouraged to implement design-based learning projects (such as RMEng), problem-based learning, and project-based learning involving simple engineering processes to enhance students' mathematical skills [76], [77]. Integrating RME into the ICT-integrated curriculum in elementary schools, along with continuous evaluation, is also necessary. This approach can help educators develop digital skills and integrate RME effectively into classroom learning.

C. Impact of RME in the Digital Era Elementary Schools

RME learning with ICT improves students' high-level thinking skills, especially geometry and track beam material [41], influences students' attitudes and abilities in mastering ellipse material [43], students' critical thinking skills with mathematics worksheets [49], High Order Thinking abilities Skills (HOTS) of students through virtual exhibition media [50], increasing mathematical competence of slow learner students [56], problem-solving abilities of students [68], increasing mathematical literacy skills through integrated RME Virtual Reality [62], problem-solving abilities, exploration, collaboration, and hands-on practice in projects in K-12 Science, Technology, Engineering, and Mathematics (STEM) in elementary schools [69], [70]. The application of RME through structured mathematics textbooks has an impact on problem-solving abilities (grade 1-3 elementary school), data concept abilities (grade 4 elementary school), data presentation abilities (grade 5 elementary school), and data processing abilities (grade 6 elementary school) [52]. Learning mathematics with web-based RME via Google Sites and MOODLE impacted student scores of 77.35 on the topics of measurement, numbering, and geometry [54]. Applying RME through symbolic interactionism and video learning in the classroom positively impacts socio-mathematical aspects (students, mathematics, and participants in mathematics classes) [66]. The application of RME is integrated with flipped learning to become Flipped Realistic Mathematics Education (F-RME), which impacts contrast abilities, the development of students' collaboration skills in working on assignments, and the effectiveness of student learning [67].

The main novelty of this research is the focus on the era of digital integration with RME in elementary schools. Most existing research on RME usually only focuses on contextual aspects of learning without exploring how digital technologies can interact in this approach. This research fills this gap by conducting systematic literature observations on how digital technology (for example, educational applications, dare learning media, and other technology-based tools) can strengthen RME strategies in mathematics classes in elementary schools. This novelty arises from combining two rapidly growing fields of study, digital education and RME, which are often researched separately. The next novelty is in the specifications for the elementary school level. Many previous studies on RME focus on secondary or tertiary education, so this research offers novelty by examining elementary schools as the primary context. The SLR research is like a literature review on the preparation of mathematics teachers at all levels [78], systematic observations of proofs in school and university mathematics education research [79], SLR study on digital learning with ChatGPT in elementary school mathematics learning [80], and a systematic review of GeoGebra in mathematics learning in junior high schools in Indonesia and Japan [81]. The findings of this research also show that the learning characteristics of elementary school students still in the cognitive development phase are different from those of students at higher levels of education. Hence, technology in this context offers unique challenges and opportunities. This research provides how RME and technology can be adapted to meet the developmental needs of elementary school students [82], [83], thus confirming that this research is very new and can be a reference for future research.

The above findings emphasize that it is necessary to integrate comparative insights from schools in developed and developing countries to implement ICT-supported RME and provide a more comprehensive perspective by considering various dimensions. In developed countries, sophisticated technological infrastructure allows interactive learning media such as Virtual Reality (VR), virtual exhibitions, and learning management systems such as MOODLE. For example, using Google Sites and MOODLE for web-based learning with high scores results in measurement, numbering, and geometry [84], [85]. In developing countries, access to technology may be limited, so implementing RME often relies on simple media such as structured textbooks and math worksheets to improve critical thinking and problem-solving skills [86].

The impact of RME, when reviewed for the future of learning in elementary schools, recommends that teacher competency and training are needed. In developed countries, teachers usually receive intensive training on educational technology, such as the use of digital tools, VR, and interactive learning applications to support High Order Thinking Skills (HOTS) skills [87], [88]. While in developing countries, training often focuses on introducing essential devices and using simple media such as learning videos and textbooks. However, integrating technology-based learning, such as flipped learning, is starting to develop in several regions [89], [90]With this comparison, the implementation of ICT-integrated RME can be adjusted to each school's needs and conditions. This approach allows for flexible curriculum development and supports the global development of students' mathematical competencies.

IV. Conclusion

RME is a mathematics learning approach that departs from the learning theory developed by Hans Freudenthal in the Netherlands in 1983, developing rapidly since 2016 which is called the mathematics pedagogy approach, and the reform of "new mathematics" to prepare students to be close to mathematical concepts and direct them to become discoverers and researcher. RME in the digital era is applied with digital mathematical tools, Hypothetical Learning Trajectory (HLT) games, virtual/digital learning, mathematics learning environments through Lesson Study for Learning Communities (LSLC), elementary school geometry learning, included in the curriculum, media, learning for numerical and computational skills, translation and reflection of mathematics through dance, technology-based learning, engineering, mathematics, learning realistic word problems and elementary school mathematics beliefs, training, application, and scientific reasoning. RME has developed into Realistic Mathematics Engineering (RMEng), integrating the RME approach with engineering design process procedures in mathematics learning in elementary schools. Indonesia, Malaysia, and Australia are the countries that implement the most RME learning integrated with digital technology. Learning RME with ICT improves high-level thinking skills on geometry and track beam material, improves students' attitudes and abilities in mastering ellipse material, increases slow learner students' mathematical competence, students' problem solving, mathematical literacy skills through integrated RME Virtual Reality, problem-solving, exploration, collaboration, and hands-on practice into elementary school STEM projects impacting problem-solving abilities (grades 1-3 elementary school), data concept abilities (grade 4 elementary school), data presentation abilities (grade 5 elementary school), and data processing abilities (grade 6 SD), student scores with a score of 77.35 on the topics of measurement, numbering, and geometry, Flipped Realistic Mathematics Education (F-RME) has an impact on contrast ability, development of students' collaboration skills in doing assignments, and student learning effectiveness. This research is timely and important for modernizing mathematics education, especially in integrating ICT tools into pedagogy. This research is limited to SLR only in the 2022-2024 period, so further research needs to be carried out exploring the theme of RME in the digital era of elementary schools with field studies according to developments in digital technology.

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