Multiple Representations in The Context of Education in The 21st Century

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ABSTRACT

Multiple representation is an important part of practically any human experience. Literature is being extensively used to study how important multiple representations are for pupils' in understanding a concept. Moreover, we explored whether particular traits in this group were related to participants, the physics concepts, or multiple representation. The eligibility requirements have been encountered in 47 articles studies from Scopus and WoS indexed articles. The review examined the Springer, Sage, Elsevier, Willey, relevant journals using a qualitative research technique. We conducted a search to find papers published from 2019 to 2024. Then, we use descriptive statistics and content analysis to analyse the data. Our qualitative content analysis revealed five key themes: multiple representations, external representations, and multiple representations in physics. The categories and frequencies have each been examined separately. We have been assessed the research's inadequacies in order to direct future efforts toward a deeper comprehension of physics phenomena. In the current reformation of physics education, multiple representation has been highlighted as a new trend in understanding a concept. As a result, the findings of this study may be used as a starting point for all stakeholders involved in physics education in the future, notably educators, professors, and researchers.

KEYWORDS

education; multiple representations; physics; research

1. INTRODUCTION

This paper employed a systematic literature review technique. A total of 47 articles were discovered from various sources such as Sage, Elsevier, Springer, Eric, etc. Nonetheless, several papers were directly searched from particular the journal since they could not be found in such database. All study was eligible since it was written in English, had Scopus/WoS indexed, and was published after 2019. Articles that accomplish the requirements have been implemented in mechanics, kinemathics, fluids, energy, and optics.

To assist understudies procure, get it, and apply arithmetic and characteristic science concepts, teachers regularly utilize and combine outside information representations. Outside representaions come in different designs, such as writings, manipulatives, activitys, sounds, pictures, charts, or equations. Distinctive outside representations may serve distinctive points (Ainsworth, 2006)they may too evoke distinctive learning forms and in this way influence what is learned (Belenky & Schalk, 2014; Lampinen & McClelland, 2018). Educational and mental analysts have broadly examined how to display, combine, and grouping numerous outside representations (MERs) to optimize learning.

This research presents a systematic literature review analysis of 47 publications published during 2019 and indexed by Scopus and WoS. The results of articles that satisfy the criteria of four keywords: multiple representation, multiple external representation, MR, and MER. An additional criterion that is the primary consideration is multiple representation in physics learning. All of the articles analysed positively influenced student learning outcomes, especially in learning physics.

This investigation aimed to map the research landscape on physics problem-solving from kindergarten to higher education after 2019. This study addresses the following research problems:

a) What is the current publishing trend in MR findings in physics?
b) What is the geographical distribution of articles published and the pattern of partnership among countries in findings related to MR in the context of physics?
c) What are the participants in MR in physics?
d) What are the research areas in MR in physics?

2. METHODOLOGY

Research Design A systematic literature review was employed as the research strategy in this study (Petticrew & Roberts, 2006). We selected 49 articles from prestigious journals published after 2019. Scopus and Web of Science index all the journals chosen (WoS). Since Scopus and Web of Science (WoS) are recognized journal indexers. The papers published on Scopus and the Web of Science (WoS) are likewise of high quality and may be accounted for. This study's purpose is to review 47 papers on problem-solving skills in physics education.

Research Procedure The review process for this study included seven steps: (1) defining the research issues (issue: multiple-representation); (2) defining the eligibility requirements (table 1); (3) generating the review protocol; (4) searching, screening, and selecting (figure 1); (5) evaluating and interpreting; (6) producing the article; and (7) publication (Bennett; et al., 2005; Borrego et al., 2014). The steps of the review process are explained in Figure 3. Inclusion criteria: The paper has been published in a peer-reviewed journal in English, the paper reports empirical and original study, the paper is in the area of problem-solving on physics education research, and the papers have been published in Scopus indexed journals or WoS.

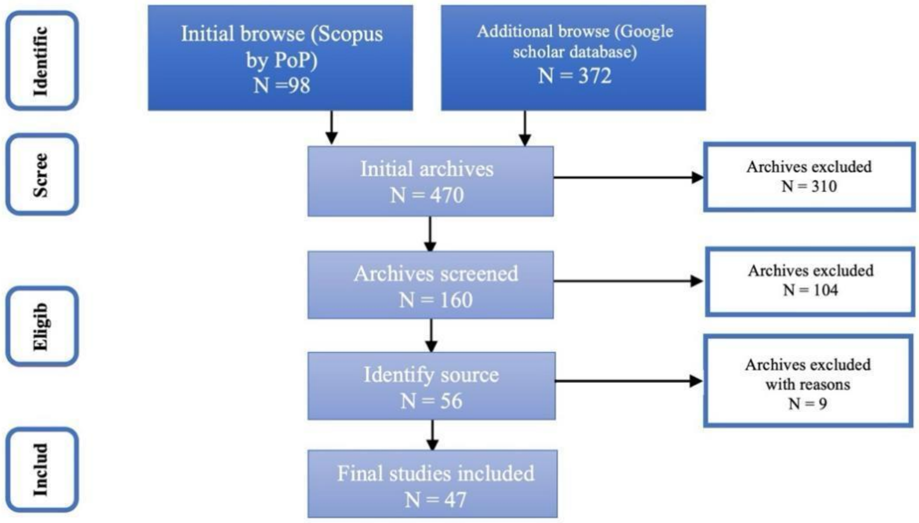

Figure 1 Flowchart of the review process

Data Collection The articles selected for review were issued from March 2019 to April 2024. The highly-regarded publishers chosen are Springer, ERIC, Taylor & Francis, Wiley, Elsevier, Emerald, Sage, etc. We likewise searched for papers on the websites of international journals. The keywords utilized were: "multiple representations," "external representation," "multiple representations on physics learning," and "Physics multiple representations" in physics education. There were about 591 articles found. However, only 47 articles met our research criteria. The shortlisted journals for review are to be found in Table 2. From Table 2, it shows that out of 24 international journals indexed by both Scopus and WoS, 8 are indexed by Scopus only, and the remaining one is indexed by WoS only. Therefore, it can be concluded that the articles chosen for this study are of good quality.

Table 1 The distribution of research based on the database

No	Journal Name	Σ	Indexed by	H-Index 2024	Country
1	Physical Review Physics Education Research (Q1)	5	Scopus & WoS	42	United States
2	International Journal of Science Education (Q1)	3	Scopus & WoS	126	United Kingdom
3	Learning and Instruction (Q1)	2	Scopus & WoS	144	United Kingdom
4	Journal of Educational Computing Research (Q1)	2	Scopus & WoS	76	United States
5	Frontiers in Psychology (Q2)	2	Scopus & WoS	184	Switzerland
6	Eurasia Journal of Mathematics, Science and Technology Education (Q2)	2	Scopus	56	Turkey

7	Research in Science Education (Q1)	2	Scopus & WoS	67	Netherlands
8	Education sciences (Q2)	2	Scopus & WoS	53	Switzerland
9	International Journal of Information and Education Technology (Q3)	2	Scopus	17	Singapore
10	European Journal of Physics (Q2)	2	Scopus & WoS	57	United Kingdom
11	International Journal of Instruction	1	WoS	-	Switzerland
12	Journal of Science Education and Technology (Q1)	1	Scopus & WoS	80	Netherlands
13	International Journal of Educational Research (Q1)	1	Scopus & WoS	80	United Kingdom
14	Educational Psychology Review (Q1)	1	Scopus & WoS	142	United States
15	International Journal of Evaluation and Research in Education (Q3)	1	Scopus & WoS	21	Indonesia
16	School Science and Mathematics (Q2)	1	Scopus & WoS	54	United States
17	European Journal of Science and Mathematics Education (Q3)	1	Scopus	7	Cyprus
18	Journal of Turkish Science Education (Q2)	1	Scopus	25	Turkey
19	Mathematics Education Research Journal (Q1)	1	Scopus & WoS	41	Netherlands
20	European Journal of Educational Research (Q2)	1	Scopus	24	Netherlands
21	Computers & Education (Q1)	1	Scopus & WoS	232	United Kingdom
22	Information (Q2)	1	Scopus & WoS	59	Switzerland
23	Frontiers in Education (Q2)	1	Scopus & WoS	40	Switzerland
24	Applied Intelligence (Q2)	1	Scopus & WoS	95	Netherlands
25	Symmetry (Q2)	1	Scopus	90	Switzerland
26	Journal of Computer Assisted Learning (Q1)	1	Scopus & WoS	114	United Kingdom
27	Teaching Exceptional Children (Q2)	1	Scopus & WoS	19	United Kingdom
28	Kasetsart Journal of Social Sciences (Q3)	1	Scopus	28	Thailand
29	Mathematical Thinking and Learning (Q1)	1	Scopus & WoS	33	United States
30	Policy Futures in Education (Q2)	1	Scopus & WoS	30	United Kingdom

31	Journal of Mathematical Behavior (Q1)	1	Scopus & WoS	58	United States
32	International Journal of Learning, Teaching, and Educational Research (Q3)	1	Scopus	18	Mauritius
33	CBE Life Sciences Education (Q1)	1	Scopus & WoS	90	United States

According to Table 2, the 47 articles we examined, came from 33 different journals, with details: 5 articles came from Physical Review Physics Education Research; 3 articles came from International Journal of Science Education; 2 articles each came from 8 journals namely (1) Learning and Instruction, (2) Journal of Educational Computing Research, (3) Frontiers in Psychology, (4) Eurasia Journal of Mathematics, Science and Technology Education, (5) Research in Science Education, (6) Education sciences, (7) International Journal of Information and Education Technology, (8) European Journal of Physics; and the last 1 article each came from the remaining 23 journals. These journals are published in various nations including United States, United Kingdom, Switzerland, Netherlands, Turkey, Singapore, Indonesia, Cyprus, Thailand, and Mauritius. All journals selected may be viewed in Scimago Journal & Country Rank (scimagojr.com). Based on Scimago Journal & Country Rank, the journals have a high H-index.

Data Analysis The data gathered in this research were evaluated descriptively. Using the predefined research framework, we categorized the data into tables and figures. The data was then thoroughly examined and synthesized with past studies. This investigation aims to look at the allocation of research based on content characteristics, projects, and discussed subjects, as well as the benefits of multiple representation in education especially physics.

3. RESULTS AND DISCUSSION

3.1. Results

The distribution of research based on research trends Figure 2 is a bar graph depicting the distribution of year publications from 2019 to 2024. During this period, most records were released in 2020 (34%), followed by 2023 (21%) and 2022 (19%). The number of multiple representation studies conducted in 2021 and 2024 is the same (11%). The last 4% of articles published in 2019.

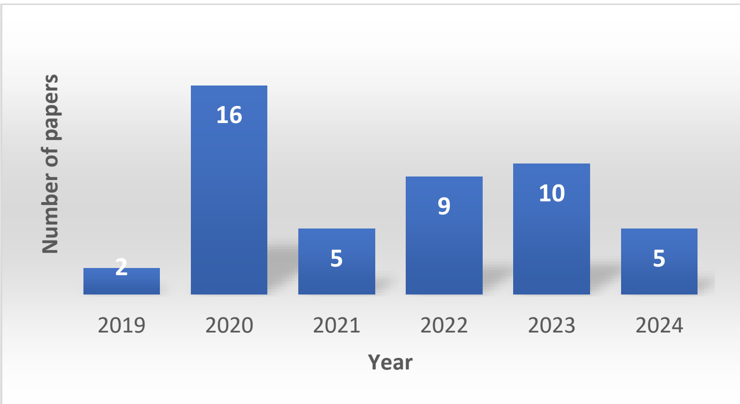

Figure 2 The distribution of research based on research trends

The number of published papers increased dramatically in 2020. The number of publications in 2020 (n = 16) increased eightfold from the previous year, namely 2019 (n =

2). A cumulative frequency graph was created to represent the growth trend of publications. This curve decreased quite drastically in 2021 (n = 5) but increased gradually in 2022 (n = 2022) and 2023 (n = 10). In 2024, it can be seen that the curve has decreased again (n = 5). However, because we only examined articles up to April 2024, we estimate that articles related to multiple representation will be widely studied and published by researchers, so that the trend in the number of publications related to this study will appear to increase at the end of 2024 compared to 2023. This shows that the expansion of research on multiple representations in physics education was quite moderate between 2018 and 2021. Nonetheless, there was a remarkable increase in research after 2022.

The distribution of research based on Geographical Data Figure 3 depicts the geographical distribution of the publications. The author's affiliations were used to identify the nations. The map's color coding indicates the distribution by the number of publications in each country. The darkest shade represents the most publications, and as the number of articles diminishes, the color lightens. The publications were spread across many regions.

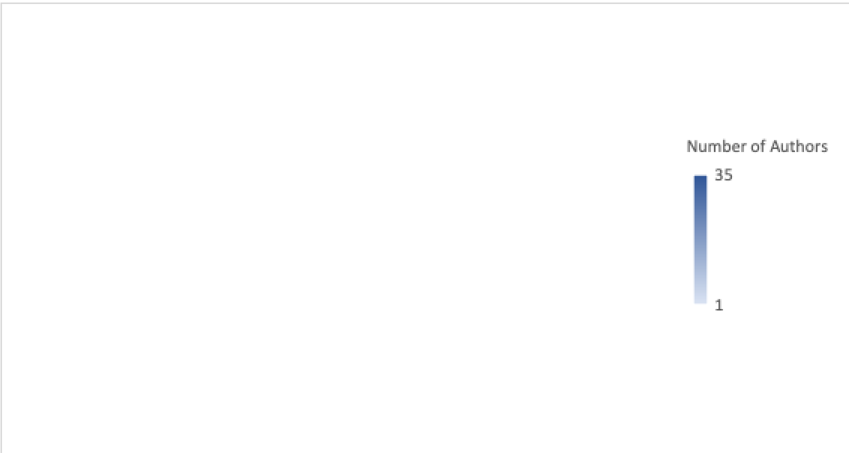

Figure 3 The distribution of research based on Geographical Data

Figure 3 depicts a map with 22 nations from the Americas (n=5 countries), Asia (n=4 countries), Europe (n=11 countries), Africa (n=1), and Australia (n=1), colored with varying intensities. The countries with the highest number of authors are Germany (n = 35), which has the darkest color, Indonesia (n = 26), and the United States (n = 22). Australia is the following country with the most significant number of authors (n = 7). This number is quite far from the United States, the third country with the most significant number of authors. Meanwhile, the remaining 18 countries have several authors that vary from 5 to 1 author, such as Mexico.

The distribution of research based on the educational stage The distribution of research based on education level can be seen in Table 3. Multiple representation in physics education research starts from kindergarten, elementary school, high school, university, and even teachers. Multi-representational research has been conducted at all levels of education. Most of the research was conducted at the university level, with 17 articles. Meanwhile, ten articles with middle school participants, 7 with high school participants, 5 with elementary school participants, 4 with teacher participants, and 1 with kindergarteners participants.

Meanwhile, the remaining three articles had elementary, middle, and high school participants. Table 2 shows fewer studies regarding dual representation at the primary and secondary school levels in the last five years. Although there has been research at the elementary school level, there has been no research at all grade levels. Therefore, multiple representations in physics learning must be explored further in elementary and middle schools.

The distribution of research based on content Almost all content in physics is related to human life. Table 3 reveals the data that earlier researchers have investigated. In addition, Table 3 presents the level of education and the number of participants seen in the articles analyzed.

Table 2 The distribution of research based on the content

No	First Author, year	Content	Education stage (n)
1	Chusni, 2022	Global warming	60 Junior high school students
2	Hochberg, 2020	Pendulum movements	52 Senior high school students
3	Becker, 2020	Uniform motion	286 Senior high school students
4	Jiang, 2021	Heat and temperature	70 Junior high school students
5	Hahn, 2023	Vector field	113 College students
6	Leisen, 2023	Force	867 6^{th}, 8^{th}, and 10^{th} grade students
7	Yinka, 2020	Projectiles and equilibrium of forces	324 Senior high school
8	Munfaridah, 2020	Electricity	College students
9	Kokkonen, 2020	Direct current (DC) circuit	4th, 5th, and 6th grade students
10	Erlina, 2023	Intermolekular forces	82 College students
11	Munfaridah, 2021	Thermodynamics	61 First-year preservice teachers
12	Conceição, 2021	Kinetic Energy	15 preservice teachers
13	Kohnle, 2020	Quantum mechanics	163 College students
14	Lucas, 2019	Mechanics	43 High school Students
15	Campos, 2020	Electric field	146 College students
16	Tomkelski, 2023	Ohm's law	4 Physics teachers
17	Abdurrahman, 2019	Energy	74 Junior high school students
18	Post, 2022	Quantum mechanics	Senior high school students
19	Mansyur, 2022	Static Fluid	6 Primary school students, 16 junior high school students, 19 senior high school students, and 16 college students

20	Nielsen, 2022	Optics	Preservice primary teacher
21	Xu, 2021	Optics	70 Primary school students
22	Liaw, 2020	Kinematics	145 College students
23	Flegr, 2023	Optics	202 Junior high school
24	Burgin, 2022	Energy	College students
25	Kokkonen, 2022	Magnetic flux	70 Senior high school students
26	Guentulle, 2024	Motion and force	49 Senior high school students
27	Geller, 2022	Diffusion	64 College students
28	Hahn, 2023	Vector field	138 College students
29	Rahmayani, 2024	Renewable energy	Senior high school students
30	Zheng, 2020	Latent specific characteristic	College students
31	Hahn, 2024	Vector field	190 College studentes
32	Koerfer, 2024	Entropy and temperature	25 College students
33	Bley, 2023	Quantum mechanics	College students
34	Alfianti, 2023	Direct current (DC) circuit	20 Senior high school students
35	Susac, 2023	Free fall, Newton's law, conservation of energy, oscillation, photoelectric effect	38 Senior high school students
36	Åhman, 2020	Heat and temperature	45 Primary school students
37	Jokić, 2020	Absolute value	226 College students
38	Malone, 2020	Linear systems of equation	63 Junior high school students
39	Jitendra, 2022	Multiplication and division	Primary school students
40	Wilson, 2021	Science	744 Primary school students
41	Chusni, 2023	Environmental change	60 Junior high school students
42	Johnson, 2020	Motion and force	College students
43	Matthews, 2022	Universal design for learning	Junior high school students
44	Zentgraf, 2024	Shape	14 Second language students
45	Vogt, 2020	Signaling principle	124 College students
46	Bakar, 2020	Concept of addition	2 pre-school students
47	Hansen, 2020	Cell division	89 Pre-service teachers, 211 adult non-educator,

	and 385 middle school students

Table 3 depicts the different forms of physics topics researched in prior research. Most of these studies concentrate on mechanical issues such as Newton's law, collision, energy, work, moment of inertia, force, simple harmonic motion, and kinematics. Furthermore, several studies are in the study of thermodynamics and electric magnets. Based on the 47 articles we examined, 38 were in the field of physics while 9 were in other fields such as computer science, mathematics, biology, and chemistry.

3.2. Discussion

This study focuses on 47 articles from internationally renowned journals on problem-solving in physics education. This study aims to take a peek at the distribution of research based on research trends, geographical data, educational stage, and content. A literature review study that analyses the distribution of research based on content parameters is consistent with past research (Winarno et al., 2020). One of the most crucial components of conducting a literature review study is analyzing the distribution of research based on the predominant characteristics of the content (Mohammadi et al., 2019; Torregrosa et al., 2023; Winarno et al., 2020).

Research on multiple representations in physics education found 47 articles since 2019. Most of the research was studied in 2020 by previous research. Research from 2021-2023 has increased. The number of articles published by Physical Review Physics Education Research since 2020, 2021, and 2022 are 124, 119, and 115 articles. This may be due to the spread of Covid-19, which limits research activities. In 2021, only eight articles were found in Scopus and WoS-indexed journals. In 2021, it is estimated that the cause is the spread of COVID-19, which makes it difficult for researchers to conduct research. Another reason is that research funds are diverted to procuring public health facilities and infrastructure (Harper et al., 2020; Pokhrel & Chhetri, 2021). However, it is evident that as time develops after COVID-19, the number of studies is increasing. It is estimated that even 2024 will experience an increase from previous years. The main criteria in searching for articles are that they come from Scopus-indexed journals and WoS-indexed Journals. Therefore, the articles reviewed were of good quality.

The distribution of authors came from 22 countries, namely Germany, Indonesia, the United States, Nigeria, Netherlands, Finland, Switzerland, Portugal, Malaysia, Nebraska, Mexico, Chile, Spain, Brazil, Australia, Taiwan, Sweden, Denmark, Croatia, Serbia, United Kingdom, and China. Of the 147 authors, 45% were from Europe, 27% were from Asia, 21% were from America, 5% were from Australia, and the remaining 2% were from Africa. Research on multiple representations is mostly studied by researchers from Europe, with the largest number of authors coming from Germany, namely 35. Physical Review Physics Education Research journal that accepts the scope of research related to multiple representations and is indexed by Scopus Q1. This is in line with the distribution of journals in Table 2 as many as five articles come from these journals. Research on multiple representations in physics education has been minimal in Australia and Africa over the past 5 years. Due to national lockdown laws, several research projects were stopped or abandoned in African higher education (Sonn et al., 2021). In addition, researchers from the African continent do not seem to be interested in problem-solving topics, especially in physics learning. This is evident from the search results on Google Scholar with the keyword multiple representations in physics in Africa. The search results show no more than ten articles that discuss the topic.

This study used students from 4 levels of education, namely elementary school, middle school, high school, and college, as well as teachers. Participants from elementary school had an age range of 10-12 years, junior high school had an age range of 12-16 years, senior high school had an age range of 16-18 years, and college had an age range of 18-35 years. 36% of the submitted articles examined multiple representations of physics at the college level. Since the participants came from all levels of education, the physics context discussed ranged from basic to complex. In the presentation of problems by physics teachers, the material should have been learned and understood by students (Docktor et al., 2016; Sormunen et al., 2020). Most of the research presented examines how successful multiple representations are in achieving success in learning; of course, the forty-seven articles mostly use different methods—ranging from multiple representations in the form of images, symbols, and videos to applications. Students need to apply multiple representations to what they learn in high school and college to overcome the problems they face in the learning process. The higher the level of education, the more complex the material studied. Perhaps this is why the context of multiple representations is widely researched at the university level. Therefore, further research is recommended to examine students' multiple representations' success at the middle and elementary school levels.

The physics materials covered are mechanical topics such as Newton's law, collision, energy, work, moment of inertia, force, simple harmonic motion, and kinematics. Furthermore, there are several studies in the study of thermodynamics and electric magnets. Based on the 47 articles we examined, 38 were in the field of physics while nine were in the other fields such as computer science, mathematics, biology, and chemistry. This is in line with the survey results of (Heller et al., 1992), who said that most of the goals of students enrolling in physics majors are to learn the basic principles of physics and reduce misconceptions about physical phenomena. Some materials go beyond physics, such as computer science, biology, chemistry, and mathematical applications.

4. CONCLUSION

One aspect that is an essential factor in realizing success in learning is the material presented. Along with the times, each student's acceptance of material is increasingly complex, starting from being based on learning speed to the most common one, which is based on learning style. In this case, the implementation of multiple representations is needed. Therefore, it is imperative to conduct a systematic literature review. This study examined the quality of materials using trend research, geographic data, education level, and content. Based on the study findings, 47 publications published between 2019 and 2024 were selected for review. As Scopus and WoS indexed them, all the selected papers were of high quality. Multiple representation has been widely applied in various countries and continues to grow every time due to its success. In addition, multiple representation is also used in learning in various subjects and even different levels of education. This research examines the spread of research topics while applying multiple representations in education, especially in physics lessons. Multiple representation has been identified as a new trend in education reform.

Moreover, multiple representation is also one of the foundations of the emerging learning philosophy of differentiated instruction. Therefore, the findings of this study can be used as a starting point for all stakeholders involved in education, especially educators, lecturers, and researchers in the future. In addition, in physics education, multiple representations can be used as one of the alternative learning strategies for understanding various formulas, graphs, and symbols in each material. Therefore, we recommend applying multiple representations in understanding physics materials with issues that previous researchers have not discussed. Further research can clarify research related to the ability to understand multiple representations in physics education.

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