Trends, challenges, and opportunities of Multiple-Representation in Science learning: a systematic literature review

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Abstract

The multiple-representation approach, central to this systematic literature review (SLR), aims to enhance the effectiveness of science learning. Conducted based on the PRISMA 2020 framework, this review analyzed 56 articles published between 2018 and 2022 from the Scopus and Web of Science (WoS) databases. The study uncovers a significant increase in the use of multiple representations to boost student understanding and engagement in science. Notably, it identifies specific challenges, such as integrating technology and pedagogical alignment, and opportunities including innovative educational tools and curriculum development. These findings bridge a critical research gap, offering valuable insights and a comprehensive guide for educators, researchers, and practitioners to meet the dynamic needs of evolving science education.

Keywords

Learning effectiveness, multiple-representation, science learning, PRISMA 2020, systematic literature review

Résumé

Cette revue systématique de la littérature (SLR), centrée sur l'approche de représentation multiple, vise à renforcer l'efficacité de l'apprentissage des sciences. Réalisée selon le cadre PRISMA 2020, cette revue a analysé 56 articles publiés entre 2018 et 2022 issus des bases de données Scopus et Web of Science (WoS). L'étude révèle une augmentation significative de l'utilisation des représentations multiples pour améliorer la compréhension et l'engagement des étudiants en sciences. Elle identifie des défis spécifiques, tels que l'intégration de la technologie et l'alignement pédagogique, et des opportunités, incluant des outils éducatifs innovants et le développement de programmes d'études. Ces découvertes comblent une lacune importante dans la recherche, offrant des perspectives précieuses et un guide complet pour les éducateurs, les chercheurs et les praticiens afin de répondre aux besoins dynamiques de l'éducation scientifique en évolution.

Mots-clés

Efficacité de l'apprentissage, représentation multiple, apprentissage des sciences, PRISMA 2020, revue systématique de la littérature

Cite this article

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Introduction

With its inherent complexity of concepts, science learning often challenges educators to seek teaching methods that can facilitate students' understanding more effectively. In recent decades, multiple representation has emerged as a promising approach, allowing students to view concepts from various perspectives (Chang et al., 2017; Gao et al., 2022). By using diverse representations such as words, numbers, symbols, images, audio, diagrams, graphics, computer simulations, mathematical equations, and so forth, students can choose and utilize representations that align best with their learning style, allowing them to connect ideas and concepts more intuitively (Ainsworth, 1999; Chang et al., 2017; Khemmani & Isariyapalakul, 2018; Malone et al., 2020; Masoudnia et al., 2019; Ulva et al., 2021; Wu & Liu, 2021). Moreover, by applying multiple representations, students are empowered to participate more actively in the learning process, develop critical thinking skills, and hone problem-solving abilities (Ainsworth, 1999; Chusni et al., 2022; Gautam et al., 2020; Munfaridah et al., 2022).

Although the multiple-representation approach offers numerous benefits for science education, its implementation in classrooms often requires special attention. One of its main challenges is integrating various forms of representation in a coherent and complementary manner (Chen et al., 2019; Frellesvig et al., 2019; Giovannini, 2019; González-Santander, 2018; Jeunehomme et al., 2022; Liu & Ding, 2019). This demands educators' deep understanding and pedagogical expertise to ensure that each representation supports and reinforces the others and is appropriate to the learning context (Bittencourt et al., 2022; Davenport et al., 2018; Lisman et al., 2017). Additionally, there are logistical challenges in developing and presenting multi-representational materials, including selecting suitable technology, training teachers, and assessing student outcomes accurately (Klein et al., 2019). However, with advancements in educational technology and ongoing research, opportunities to refine and optimize this approach are increasing. Through a systematic literature review, this study explores how educators and researchers have navigated these challenges and sought innovative solutions to maximize the potential of multiple representations in science learning.

Research related to multiple representation has been extensively conducted, including the influence of multiple representation on students' learning motivation (Rasmawan, 2020; Widarti et al., 2021), student outcomes (Dehghan et al., 2019; Kara & İncikabi, 2018), critical thinking (Danday & Monterola, 2019; Fratiwi et al., 2019; Mahardika et al., 2020), and problem-solving (Bajracharya et al., 2019; Bakar et al., 2020; Benslimane et al., 2003; Chang et al., 2017; Kim & Lee, 2021; Moore et al., 2020; Mu & Xu, 2019; Sutriani & Mansyur, 2021; Taqwa et al., 2020; Tima & Sutrisno, 2018; Yaghoobzadeh & Schütze, 2018; Yuniati et al., 2019). However, there has yet to be a study examining the entirety of research related to multiple-representation in science learning across all educational levels (from early childhood to higher education) using a systematic literature review.

This study investigates the trends, challenges, and opportunities of multiple representations in the context of science learning through a systematic literature review approach. The emergence of multiple representations in science education highlights a critical avenue for enhancing learning experiences. However, current research reveals gaps in understanding and applying these methods, particularly in integrating them into curricula. This study aims to bridge this gap, providing valuable insights for education and curriculum design by presenting a comprehensive overview of issues related to the application of multiple representations. By exploring the extent and manner of employing multiple representations in recent scientific educational research, this study contributes to a deeper understanding, facilitating their effective use in educational settings. The focus is on articles published in Scopus and Web of Science between 2018 and 2022, addressing key research questions on challenges, opportunities, and trends in the use of multiple representations over the past five years. The three main research questions underpinning this study are:

- RQ 1: How have research trends related to multiple-representation in science education research developed over the past five years?
- RQ 2: What challenges arise when implementing multiple-representation in science education research?
- RQ 3: What are the opportunities for further research regarding multiple representations in the context of science education research?

Methodology

The Systematic Literature Review (SLR) approach was chosen as it allows for transparently investigating the strengths and limitations of previous research and can uncover specific research gaps (O'Reilly et al., 2022). The literature presented in this report follows procedures outlined in the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA). PRISMA was published in 2009 and is designed to assist in transparently reporting research findings to identify, select, evaluate, and synthesize studies (Page et al., 2021). This PRISMA protocol supports quality and rigor when reporting academic literature (O'Reilly et al., 2022).

The articles analyzed in this Systematic Literature Review were obtained by searching Scopus and Web of Sciences online databases, followed by several selections to obtain the appropriate analysis criteria. An initial search was conducted in the Scopus and Web of Science databases using the keyword «multiple-representation» limited to the last five years, journal article types in English related to mathematics, physics, biology, or chemistry in educational research. The results of this selection were then systematically analyzed using reviews presented in tables and graphs.

Search Strategy

A search in the Scopus database with the keyword «multiple-representation» yielded 524 documents, which, when limited from 2018-2022, resulted in 185 documents. These five years were selected to ensure the inclusion of the most recent and relevant studies in the rapidly evolving field of science education, where trends and methodologies can change significantly over short periods. Further narrowed down to only journal articles, 84 documents were found. By limiting only to the English language, 83 documents were identified. To encompass the broad application of multiple representations beyond the explicit mention in titles or keywords, a thorough review of abstracts and methodologies was conducted. This allowed for the inclusion of studies that implicitly employed multiple-representation approaches in science learning. After excluding literature analysis research types and those unrelated to science, learning mathematics, physics, biology, chemistry, or educational research, 49 documents remained. Meanwhile, a search on the Web of Science produced 53 documents. After selecting only those articles pertinent to multiple representations in the context of educational research related to mathematics, physics, biology, or chemistry, only seven articles remained. The search was categorized as journal articles in the last five years (2018-2022) based on the keyword «multiple-representation» across two databases, namely:

1. Web of Science (WoS) - 53 articles found, 46 articles excluded, resulting in 7 articles
2 Scopus - 185 articles found, 136 articles excluded, resulting in 49 articles.

Thus, 56 documents were analyzed. In addressing the application of multiple representations in both mathematics and science, the study recognizes the shared principles and distinct nuances in each field. This recognition informs a more nuanced analysis of the data, acknowledging the interdisciplinary nature of multiple representations while focusing on their specific applications in science education.

Eligibility Criteria

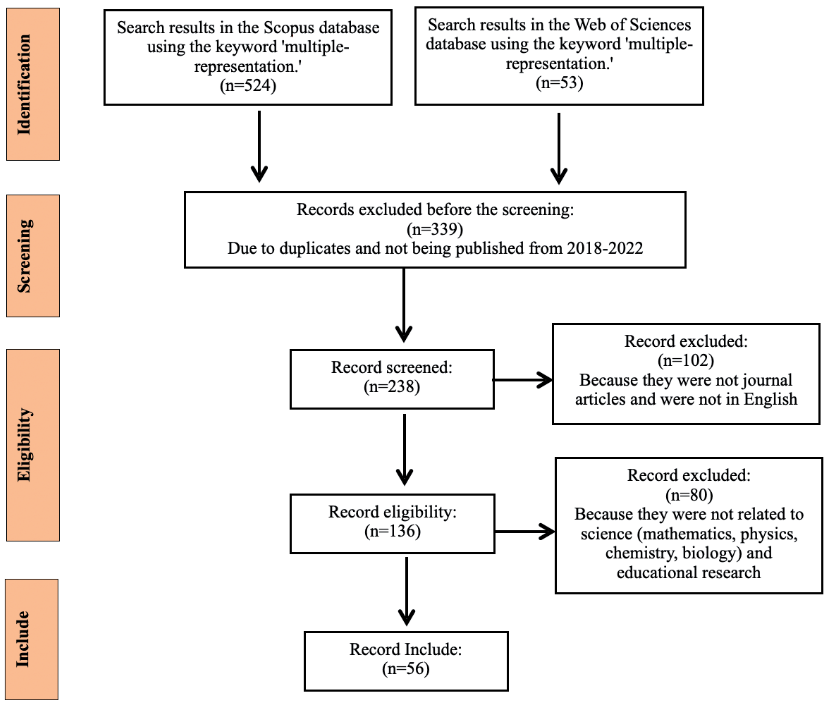
Eligibility criteria were used to review inclusion and exclusion criteria, which were then categorized for analysis (Page et al., 2021). We could select research studies relevant to «multiple-representation» within educational research by selecting criteria. The eligibility criteria were:

1. Published in the last five years (2018-2022).
2. Journal article type.
3. Written in English.
4 Concerns 'multiple-representation' specifically and not just 'multiple' or 'representation'.
5. Multiple representations related to science (physics, chemistry, and biology) in educational institutions.
6. Multiple-representation included in research in the field of education (educational research).

Exclusion Criteria

Strict inclusion criteria were established to ensure direct relevance to the topic of multiple representations in science learning. This involved assessing titles, abstracts, and keywords for their relation to the research questions. Subsequently, the selected articles underwent an in-depth qualitative evaluation to ensure that they provide substantial insights into the trends, challenges, and opportunities in the application of multiple representations. This process enabled the identification of the most relevant and informative articles, resulting in a comprehensive and accurate synthesis of the research.

FIGURE 1



Study Selection Chart Adapted from the PRISMA 2020 Framework (Page et al., 2021)

The inclusion criteria used in this research were:

1. Duplicates.
2. Published before 2018.
3. Not written in English.
4. Types like conference proceedings, book sections, book chapters, books, magazine articles, newspaper articles, theses, web pages, review articles, early access articles, editorial meetings, meeting abstracts, and letter.
5. Literature reviews, bibliometric analyses, meta-analyses, or descriptive analysis types.
6. Outside the 'multiple-representation' topic.
7. Science not related to school settings.
8. Outside of educational research.

From the PRISMA selection chart process, through the screening and eligibility stages, 56 articles were identified that needed to be reviewed and analyzed. As a result, 521 articles were excluded. The following factors led to the exclusion of these 521 articles:

1. 339 articles were removed as they were not research published in the last five years (2018-2022).
2. 101 articles were removed because they were not journal articles.
3. 1 article was removed as it was not reported in English.
4. 80 articles were removed as they were unrelated to science (mathematics, physics, chemistry, and biology) and educational research.

Thus, from this selection, 56 articles were retained for analysis on data characteristics, research type, challenges, opportunities, and trends over the past five years related to the topic of 'multiple-representation.' It was limited to educational research in science (mathematics, physics, chemistry, and biology).

Findings and discussion

The systematic literature review was conducted on 56 articles published from 2018 to 2022, focusing on 'multiple-representation' limited to educational research in science (mathematics, physics, chemistry, and biology) to address three research questions. The details of the 56 articles utilized in this article are as follows:

Table 1

List of the 56 selected articles reviewed in this study

ID	Year	Title	Author	Journal
1	2018	A New Form of Understanding Maps: Multiple Representations with Pirie and Kieren Model of Understanding	Nurgul Duzenli Gokalp and Safure Bulut	International Journal of Innovation In Science and Mathematics Education
2	2018	An Investigation of Pattern Problems Posed by Middle School Mathematics Preservice Teachers Using Multiple Representation	Yasemin Yilmaz, Soner Durmus, and Hakan Yaman	International Journal of Research in Education and Science
3	2018	Effect of Using Problem-Solving Model Based on Multiple Representations on the Students' Cognitive Achievement: Representations of Chemical Equilibrium	Maria Tesiana Tima and Hari Sutrisno	Asia-Pacific Forum on Science Learning and Teaching
4	2018	Improvement of Algebraic Thinking Ability Using Multiple Representation Strategy in Realistic Mathematics Education	Widya Kusumaningsih, Darhim, Tatang Herman, and Turmudi	Journal on Mathematics Education

ID	Year	Title	Author	Journal
5	2018	Knowledge Organization through Multiple Representations in a Computer-Supported Collaborative Learning Environment	Bahadir Namdar and Ji Shen	Interactive Learning Environments
6	2018	Learning with Multiple Representations: Infographics as Cognitive Tools for Authentic Learning in Science Literacy	Engida Gebre	Canadian Journal of Learning and Technology
7	2018	Magnetic Force Learning with Guided-Inquiry and Multiple Representations Model (GIMuR) to Enhance Students' Mathematics Modeling Ability	Siska Desy Fatmaryanti, Suparmi, Sarwanto, Ashadi, and Heru Kurniawan	Asia-Pacific Forum on Science Learning and Teaching
8	2018	Sixth-grade Students' Preferences on Multiple Representations Used in Fraction Operations and Their Performance in Their Preferences	Fatma Kara and Lütfi İncikabi	Elementary Education Online
9	2018	Sixth-grade Students' Skills in Using Multiple Representations in Addition and Subtraction Operations in Fractions	Fatma Kara and Lütfi İncikabi	International Electronic Journal of Elementary Education
10	2018	The Effect of Multiple Representation-based Learning (MRL) to Increase Students' Understanding of Chemical Bonding Concepts	Sunyono and Annisa Meristin	Jurnal Pendidikan Ipa Indonesia
11	2018	The Importance of Multiple Representations of Mathematical Problems: Evidence from Chinese Preservice Elementary Teachers' Analysis of a Learning Goal	Rui Kang and Di Liu	International Journal of Science and Mathematics Education
12	2019	Study of Concept Mastery of Binocular K-11 Students through the Implementation of a Multi-Representative Approach	Nuzulira Janeusse Fratiwi, Setiya Utari, and Achmad Samsudin	International Journal of Scientific and Technology Research
13	2019	Comparison of Algorithmic and Multiple-Representation Integrated Instruction for Teaching Fractions, Decimals, and Percent	Raymond Flores, Fethi A. Inan, Sunyoung Han, and Esther Koontz	Investigations in Mathematics Learning
14	2019	Effects of Microteaching Multiple-Representation Physics Lesson Study on Preservice Teachers' Critical Thinking	Billy A. Danday and Sheryl Lyn C. Monterola	Journal of Baltic Science Education
15	2019	Examination of Conceptual Knowledge of Freshmen Classroom Teacher Candidates on Function in the Context of Multiple Representations	Mohammet Doruk	International Journal of Research in Education and Science

ID	Year	Title	Author	Journal
16	2019	Implementing Multiple Representation-based Worksheets to Develop Critical Thinking Skills	Abdurrahman, Cris Ayu Setyaningsih and Tri Jalmo	Journal of Turkish Science Education
17	2019	Multiple Representations' Ability in Solving Word Problems	Nurrahmawati, Cholis Sa'dijah, Sudirman, and Makbul Muksar	International Journal of Recent Technology and Engineering
18	2019	Multiple Representations in the Development of Student's Cognitive Structures about the Saponification Reaction	Mónica Baptista, Iva Martins, Teresa Conceição, and Pedro Reis	Chemistry Education Research and Practice
19	2019	Profiling the Combinations of Multiple Representations Used in Large-Class Teaching: Pathways to Inclusive Practices	João Elias Vidueira Ferreira and Gwendolyn Angela Lawrie	Chemistry Education Research and Practice
20	2019	The Analysis of Concept Mastery Using Redox Teaching Materials with Multiple Representations and Contextual Teaching-Learning Approach	Susilaningsih E., Lastri L., Drastisianti A., Kusumo E., and Alighiri D.	Jurnal Pendidikan IPA Indonesia
21	2019	The Use of Multiple Representations in Functional Thinking	Suci Yuniati, Toto Nusantara, Subanji, and I Made Sulandra	International Journal of Recent Technology And Engineering
22	2019	University Chemistry Students' Interpretations of Multiple Representations of the Helium Atom	Zahilyn D. Roche Allred and Stacey Lowery Bratz	Chemistry Education Research and Practice
23	2019	Students' Strategies for Solving a Multi-Representational Partial Derivative Problem in Thermodynamics	Rabindra R. Bajracharya, Paul J. Emigh, and Corinne A. Manogue	Physical Review Physics Education Research
24	2020	Abstraction through multiple representations in an integrated computational thinking environment	Aakash Gautam, Whitney E. Wall Bortz and Deborah Gail Tatar	Technical Symposium on Computer Science Education
25	2020	Development of a multi-representation-based electronic book on intermolecular forces (IMFs) concept for prospective chemistry teachers	Rahmat Rasmawan	International Journal of Instruction
26	2020	An Essay on Proof, Conviction, and Explanation: Multiple Representation Systems In Combinatorics	Elise Lockwood, John S. Caughman, and Keith Weber	Educational Studies in Mathematics

ID	Year	Title	Author	Journal
27	2020	Learning Electric Circuit Principles in a Simulation Environment with a Single Representation Versus "Concreteness Fading" through Multiple Representations	Tomi Jaakkola and Koen Veermans	Computers and Education
28	2020	Multiple Representations in Computational Thinking Tasks: A Clinical Study of Second-Grade Students	Tamara J. Moore, Sean P. Brophy, Kristina M. Tank, Ruben D. Lopez, Amanda C. Johnston, Morgan M.Hynes and Elizabeth Gajdzik	Journal of Science Education and Technology
29	2020	Problem-Based Learning Strategies Using Multiple Representations and Learning Styles to Enhance Conceptual Understandings of Chemistry	Ida Ayu Anom Arsani, Punaji Setyosari, and Wayan Dasna	Periodico Tche Quimica
30	2020	Students Understanding of the Electric Field Concept through Conversions of Multiple Representations	Esmeralda Campos, Genaro Zavala, Kristina Zuza, and Jenaro Guisasola	Physical Review Physics Education Research
31	2020	Teaching and Learning Science Through Multiple Representations: Intuitions and Executive Functions	Janice Hansen and Lindsey Engle Richland	CBE Life Sciences Education
32	2020	The Effect of Multiple Representations of Physical and Chemical Changes on the Development of Primary Preservice Teachers Cognitive Structures	Aysegül Derman, and Jazlin Ebenezer	Research in Science Education
33	2020	The Role of Professional Knowledge for Teachers' Analysis of Classroom Situations Regarding the Use of Multiple Representations	Marita Eva Friesen, and Sebastian Kuntze	Research in Mathematics Education
34	2020	The Use of Multiple Representations in Understanding Addition: The Case of Preschool Children	Kamariah Abu Bakar, Suziyani Mohamed, Faridah Yunus, and Aidah Abdul Karim	International Journal of Learning, Teaching, and Educational Research
35	2020	Using Smartphones As Experimental Tools-A Follow-Up: Cognitive Effects by Video Analysis and Reduction of Cognitive Load by Multiple Representations	Katrin Hochberg, Sebastian Becker-Genschow, Malte Louis, Pascal Klein, and Jochen Kuhn	Journal of Science Education and Technology

ID	Year	Title	Author	Journal
36	2021	Impact of Multi-Representation-Based Video on Students' Learning Outcome	A Halim, N Husna, Samsul, Evendi, Nurulwati, E Mahzum and I Irwandi	South East Asia Science, Technology, Engineering, and Mathematics International
37	2021	Graphic Representation Ability in Learning Chemistry through Multi-Presentation-Based Chemistry Modules	Y I Ulva, I K Mahardika and Nuriman	Physics and Mathematics for Biological Science
38	2021	Analysis Of Students' Multi-Representation Ability in Augmented Reality-Assisted Learning	Sri Jumini, Edy Cahyono and Muhammad Miftakhul Falah	Library Philosophy and Practice
39	2021	Developing Integrated Triplet Multi-Representation Virtual Laboratory in Analytic Chemical Materials	Hayuni Retno Widarti, Deni Ainur Rokhim, M.Muchson, and Endang Budiasih	International Journal of Interactive Mobile Technologies
40	2021	Lesson Study as a Means to Change Secondary Preservice Physics Teachers' Practice in the Use of Multiple Representations in Teaching	Teresa Conceição, Mónica Baptista, and João Pedro Ponte	Education Sciences
41	2021	Eye-Movement Study of High- and Low-Prior-Knowledge Students' Scientific Argumentations with Multiple Representations	Chao-Jung Wu and Chia-Yu Liu	Physical Review Physics Education Research
42	2021	Differences between Professionals and Students in Their Visual Attention on Multiple Representation Types while Solving an Open-Ended Engineering Design Problem	Ananna Ahmed, David S Hurwitz,Sean Gestson, and Shane A Brown	Physical Review Physics Education Research
43	2021	Effectiveness of Multimedia Based on Multiple Representations of Hess' Law: Concept and Skills of Preservice Science Teachers	Wilda Syahri, Yusnaidar, Muhaimin, and Akhmad Habibi	International Journal of Instruction
44	2021	Exploring Students' Translation Performance and Use of Intermediary Representations among Multiple Representations: Example from Torque and Rotation	Jih Yuan Chang, Meng-Fei Cheng, Shih-Yin Lin, and Jang-Long Lin	Teaching and Teacher Education

ID	Year	Title	Author	Journal
45	2021	Multiple Representation-Based Learning Through Cognitive Dissonance Strategy to Reduce Student's Misconceptions in Volumetric Analysis	Hayuni Retno Widarti, Anna Permanasari, Sri Mulyani and Deni Ainur Rokhim	TEM Journal
46	2021	Multiple Representations and Mathematical Creativity	Ali Bicer	Thinking Skills and Creativity
47	2021	Promoting Senior Primary School Student's Understanding of the Particulate Nature of Matter through Inquiry Instruction with Multiple Representations	Emine Adadan and Müjde Müge Ataman	Education
48	2021	Relationships between Facial Expressions, Prior Knowledge, and Multiple Representations: A Case of Conceptual Change for Kinematics Instruction	Hongming Liaw, Yuh-Ru Yu, Chin-Cheng Chou and Mei-Hung Chiu	Journal of Science Education and Technology
49	2021	The Use of Multiple Representations in Undergraduate Physics Education: What Do We Know and Where Do We Go from Here?	Nuril Munfaridah, Lucy Avraamidou, and Martin Goedhart	Eurasia Journal of Mathematics, Science, and Technology Education
50	2022	Categorizing Teachers' Gestures in Classroom Teaching: From the Perspective of Multiple Representations	Qingtang Liu, Ni Zhang, Wenli Chen, Qiyun Wang, Yangyang Yuan, and Kui Xie	Social Semiotics
51	2022	Preservice Physics Teachers' Development of Physics Identities: The Role of Multiple Representations	Nuril Munfaridah, Lucy Avraamidou, and Martin Goedhart	Research in Science Education
52	2022	Empowering Critical Thinking Skills on Different Academic Levels through Discovery-Based Multiple-Representation Learning	Muhammad Minan Chusni, Sulistyo Saputro,Suranto and Sentot Budi Rahardjo	Cakrawala Pendidikan: Jurnal Ilmiah Pendidikan
53	2022	Enhancing Critical Thinking Skills of Junior High School Students Through Discovery-Based Multiple Representations Learning Model	Muhammad Minan Chusni, Sulistyo Saputro, Suranto and Sentot Budi Rahardjo	International Journal of Instruction

ID	Year	Title	Author	Journal
54	2022	Task Design for Graphs: Rethink Multiple Representations with Variation Theory	Heather Lynn Johnson	Mathematical Thinking and Learning
55	2022	Using Multiple Representations to Foster Multiplicative Reasoning in Students with Mathematics Learning Disabilities	Jitendra, Asha K. Dougherty, Barbara, Sanchez, Victoria, and Suchilt, Luisana	Teaching Exceptional Children
56	2022	Meaning Making with Multiple Representations: A Case Study of A Preservice Teacher Creating a Digital Explanation	Wendy Nielsen, Annette Turney, Helen, Georgiou and Pauline Jones	Research in Science Education

Trends

Several intriguing and significant trends regarding using multiple representations in science learning have been identified. These trends reveal the latest developments in science learning that involve multiple representations and have the potential to make a substantial impact in the field. These trends reflect ongoing efforts to enhance the quality of science learning. The research trends of multiple representations in sciences within educational research over the past five years (2018-2022) are presented in Table 2.

TABLE 2

Trends in Multiple-Representation research

Trends	Paper ID from Table 1	Frequency
Research on multiple representations in motivation and learning outcomes.	8, 9, 25, 30, 31, 35, 36, 43, 45, 48	10
Investigating the use of multiple representations to enhance problem-solving abilities.	3, 11, 17, 21, 23, 27, 34, 39, 42, 44, 49	11
Exploring the impact of multiple representations on affective and cognitive domains.	2, 3, 5, 6, 13, 17, 18, 25, 26, 28, 32, 33, 35, 37, 38, 40, 41, 43, 45, 50	20
Probing the influence of multiple-representation on thinking skills and understanding.	1, 4, 7, 10, 12, 14, 15, 16, 19, 20, 21, 22, 24, 29, 34, 45 46, 47, 50, 51, 52, 53, 54, 55, 56	26

Recent trends in science education research highlight the growing significance of multiple representations. This approach extends beyond traditional learning, fostering motivation and deeper engagement in students. A noticeable shift from mere content mastery to enhancing problem-solving abilities has been observed. Studies indicate that multiple representations not only aid in grasping existing knowledge but also encourage the development of innovative problem-solving strategies.

Furthermore, research emphasizes the dual impact of multiple representations on both affective and cognitive domains of learning. This holistic approach has proven beneficial in engaging a broader spectrum of students, including those with special needs. The utilization of multiple representations is shown to actively involve students, catering to diverse learning styles and needs. This inclusive tool not only addresses cognitive aspects but also nurtures emotional engagement in science learning.

Another significant area of research focuses on the influence of multiple representations on critical thinking and understanding. It's been observed that this approach remarkably enhances higher-order thinking skills like analysis, evaluation, and synthesis. The ability to think critically and comprehend concepts deeply is further reinforced when students engage with multiple forms of representation. Additionally, it's found that students exposed to multiple representations exhibit improved conceptual understanding compared to those who learn with a single form of representation.

This paradigm shift in science education is increasingly orienting towards the development of 21st-century skills such as problem-solving and critical thinking. The evolving nature of education demands adaptive and versatile teaching approaches, where multiple representations play a pivotal role. The ongoing research underscores the need for an interdisciplinary approach to science learning, integrating various aspects of learning across different scientific fields.

The integration of multiple representations in science education is proving to be a vital element in preparing students for the challenges of the modern world. It encourages a deeper and more inclusive learning experience, equipping students with essential skills to navigate and adapt to a rapidly changing environment. The future of science education lies in embracing this multifaceted approach, continually evolving and adapting to meet the dynamic needs of students and the educational landscape.

Challenges

Research on multiple representations in science learning has demonstrated substantial potential in enhancing students' understanding of scientific concepts. However, as with many learning innovations, its implementation has challenges that must be addressed to maximize its effectiveness. Out of the 56 articles analyzed, five research challenges were identified in studying multiple representations in sciences within educational research. These challenges are presented in Table 3.

Table 3

Challenges in Multiple-Representation Research

Research Challenges	Paper ID from Table 1	Frequency
Availability and proficiency in using technology for learning.	5, 14, 35, 56	4
Length of preparation and instruction.	4, 40, 14	3
In-service teacher training for the implementation of multiple representations as a teaching strategy.	4, 34, 45	3
Pedagogical competence of prospective teachers.	8, 9, 51, 54	4
Cognitive load.	20, 30, 41, 49	4

Implementing multiple representations in science education faces several challenges. The first is technology availability and usage capability. While urban schools often have better infrastructure, rural and resource-limited schools struggle to acquire and effectively integrate technology, limiting their ability to implement diverse learning methods (Hamzeh et al., 2019; Wang et al., 2018). Additionally, teacher and student familiarity with technology is a hurdle, as both groups may lack the skills to effectively utilize digital resources (Guntara & Utami, 2021; Ranellucci et al., 2020). The second challenge is the extensive preparation and instruction time required for multiple representations. This approach demands significant teacher effort in preparing diverse resources and managing classroom interactions, often leading to time constraints and potential teacher overwhelm (Alter & Haydon, 2017; Munfaridah et al., 2021). The third challenge involves in-service teacher training. Teachers often feel ill-equipped to implement multiple representations due to insufficient training, which is further compounded by the optional nature of such programs (Permatasari et al., 2022). The fourth challenge is ensuring prospective teachers' pedagogical competence. Teacher education programs need to focus more on innovative teaching methods, like multiple representations, to prepare candidates for contemporary educational challenges (Klein et al., 2019; Permatasari et al., 2022). The final challenge is managing cognitive load. Multiple representations can overwhelm students if not carefully selected and integrated (Hahnel et al., 2019; Klein et al., 2019).

To address these challenges, a multifaceted approach is needed. For technology integration, schools can explore partnerships with tech companies and educational nonprofits to improve access and training. Tailored professional development programs can empower teachers with both technical skills and pedagogical strategies for effective technology use (Heitink et al., 2017; Penuel et al., 2007; Shaukat et al., 2018). Regarding time constraints, schools could consider allocating dedicated time for teachers to develop multiple-representation materials and strategies. Collaboration among teachers can also be encouraged to share resources and reduce individual workload. For in-service teacher training, embedding continuous, practice-based training within the school calendar can ensure regular upskilling (Ahmed et al., 2021; Forlin & Sin, 2017). Prospective teacher training programs should integrate current educational technologies and methodologies into the curriculum, providing hands-on experience with multiple representations. Finally, to manage cognitive load, educators should be trained to select and sequence representations thoughtfully, focusing on coherence and relevance to learning objectives (Kadir et al., 2023; Naismith et al., 2015). Regular student feedback can guide adjustments in teaching approaches. Addressing these challenges requires a concerted effort from educational stakeholders at all levels, promising a richer and more inclusive learning environment for students.

Opportunities

Alongside educational and technological developments, opportunities to explore and develop multiple-representation-based learning are expanding. Six research opportunities were identified from the analysis of 56 articles. These opportunities are presented in Table 4.

TABLE 4

Opportunities in Multiple-Representation research

Opportunities	Paper ID from Table 1	Frequency
Multiple-representation research in the psychomotor domain.	3, 8, 9, 37, 38, 44	6
Development of multiple-representation-based multimedia learning integrated into engaging learning models.	10, 25, 34, 39, 43, 56	6
Advanced multiple-representation research concerning mathematical reasoning, creativity, and modeling capabilities.	7, 34, 46, 52, 53, 54	6
Multiple-representation research on computational skills and thinking.	25	1
Development of learning objectives oriented towards multiple representations.	11	1
Implementation of multiple representations at the preschool and disability school levels.	34, 55	2

The first research opportunity concerning multiple-representation in the psychomotor domain extends the boundaries of multiple-representation learning beyond merely the cognitive and affective realms. In science education, multiple representations usually focused on visualization and concept comprehension, can be extended to the psychomotor domain by integrating physical activities supporting conceptual understanding.

For example, when studying physics concepts about motion, students can leverage physical simulations while simultaneously performing certain physical movements related to the studied concept. This deepens their understanding and assists in information retention (Zakirman et al., 2022). Moreover, combining visual representations (like diagrams or 3D models) with laboratory activities can enhance students' practical and conceptual skills (Lamanepa et al., 2022). Research opportunities include developing effective instructional methods, evaluating the impact of integrating the psychomotor domain with multiple representations on learning outcomes, and exploring supporting technologies, such as virtual or augmented reality.

The second research opportunity relates to multimedia learning. In the rapidly advancing information technology era, the potential of multimedia in multiple-representation-based learning is becoming increasingly relevant and vital. Multimedia integrated with multiple representations can enhance student engagement and comprehension, especially in abstract science concepts (Chen & Gladding, 2014). Well-designed multimedia can facilitate students' cognitive processes, enabling them to integrate information from various sources and reinforce understanding (Arifin et al., 2020). One significant advantage of this approach is its flexibility. Students can tailor their learning experience based on their needs and preferences. Multiple-representation-based multimedia can increase student engagement and motivation, especially when materials cater to individual needs (Riska & Guspatni, 2022). Research opportunities here involve exploring new technologies, evaluating the effectiveness of different multimedia formats in learning contexts, and developing design methods that maximize the potential of multiple representations, providing rich, adaptive, and responsive learning experiences tailored to student needs.

The third opportunity relates to multiple-representation research on mathematical reasoning, creativity, and modeling abilities. Multiple representations allow students to view concepts from diverse perspectives, facilitating deeper comprehension and more critical reasoning. Students taught with the multiple-representation approach demonstrate better reasoning capabilities compared to those using only traditional methods (Mutia & Prasetyo, 2018). Furthermore, mathematical creativity emphasizes students' ability to apply mathematical concepts and techniques innovatively. Using various representations, students get opportunities to experiment and seek solutions that might not have been evident in traditional teaching. The multiple-representation approach fosters lateral and creative thinking in mathematical problem-solving (Hendriana & Fadhillah, 2019). Additionally, with the aid of technology, multiple representations can assist students in visualizing and comprehending the practical applications of mathematical theories. As a result, numerous emerging research opportunities, given the importance of these skills in modern mathematical education, necessitate more empirical studies and teaching method developments.

The fourth opportunity pertains to multiple-representation research on computational abilities and thinking. Implementing multiple representations in this context can introduce novel ways to comprehend and teach complex concepts in computational thinking. This approach can enhance students' understanding of algorithms and facilitate knowledge transfer to real-life situations (Widarti et al., 2019b). Implementing multiple representations in computational thinking education is relatively new. Consequently, there is a significant opportunity for research concerning its effectiveness, instructional design, and the impact assessment of this approach in computational education. The multiple-representation approach in computational thinking education offers an opportunity to augment students' understanding and skills in programming and other computational concepts.

The fifth opportunity revolves around developing learning objectives oriented towards multiple representations. The multiple-representation approach enables students to understand concepts from diverse modalities and perspectives. By defining learning objectives that mirror this, teachers can provide a clear roadmap for students regarding how various representations interrelate and how they can be collectively used to bolster understanding. Multiple-representation-oriented learning objectives can enhance student engagement and foster a deeper conceptual understanding (Bologna et al., 2022; Supasorn, 2015). Such objectives can also support instructional differentiation (Rau, 2016). Students get the autonomy to select the representations they prefer for learning. The development of multiple-representation-oriented learning objectives offers a chance to elevate the quality and relevance of education while accommodating the diverse learning needs of students.

The final opportunity concerns implementing multiple representations at the preschool and disability school levels. Multiple representations can be a potent tool to support inclusive learning and instructional differentiation (Klein et al., 2019; Rau, 2016). At the preschool level, children tend to learn effectively through direct experiences and interactions with their surroundings. In this context, multiple representations can offer various ways for children to explore and grasp basic concepts. Utilizing images, physical objects, and kinesthetic activities can foster a profound conceptual understanding at this stage (Mardiansyah et al., 2022; Supasorn et al., 2022).

In disability schools, students face multiple learning barriers, ranging from cognitive challenges to physical limitations. Multiple representations provide flexibility to adapt learning materials to the specific needs of these students. Integrating the multiple-representation approach in schools for students with special needs significantly improves student engagement and understanding (Saputra et al., 2019; Widarti et al., 2019a; Wiyarsi et al., 2018). Therefore, there is a pressing need for further research on designing and effectively implementing multiple-representation learning for this student population. Multiple-representation learning can offer more inclusive and student-oriented education at preschool and disability school levels. From these opportunities, multiple representations present a diverse and rich research horizon. With heightened educational needs awareness and technological advancements, this approach can revolutionize teaching methods in the future.

Conclusion and recommendations

As education research progresses, multiple representations have shown significant growth in supporting the learning process, especially in science education. Literature analysis indicates certain tendencies in multiple-representation applications based on the scientific field, with varied focuses from learning motivation to conceptual understanding. While this approach holds immense potential, challenges like technology availability, teacher training needs, and cognitive load also merit consideration. However, accompanying these challenges are opportunities for innovation, especially in developing multimedia learning resources, integrating computational thinking, and applying it in early and inclusive education.

It is important to acknowledge the limitations of this study. The scope was confined to articles published between 2018 and 2022, which may have excluded relevant research from earlier periods that could provide additional insights into the evolution of multiple representations in education. Furthermore, the focus on journal articles indexed in Scopus and Web of Science may have omitted valuable contributions from other sources. Given the findings, educational institutions should consider an instructional design approach integrating multiple representations with effective pedagogical techniques. In-service teacher training is essential, equipping prospective teachers with the skills and understanding to effectively implement this approach. Moreover, adopting technology supporting multiple representations should be judiciously considered, ensuring it meets learning needs without adding undue cognitive load on students. Finally, there is an urgency for more in-depth research to provide insights into the optimal application of multiple representations, especially in adaptive and inclusive educational contexts, and interdisciplinary collaboration for further innovation in this domain.

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