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Improving Representational Competence in Physics Education: A Systematic Review and Future Research Directions

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Abstract: Several studies have been conducted to improve students' representational competence in physics, but a comprehensive review of these efforts is lacking. This manuscript summarizes current knowledge, identifies gaps, and suggests future research directions to improve students' representational competence. A review of 26 scientific articles from 2000 to 2023 in physics education journals was conducted. The findings revealed that (a) a consistent learning approach can improve students' representation competence, (b) constructivist-based learning models show a significant impact on the understanding of various forms of representation, (c) interactive learning media, such as simulations and animations, are more effective than conventional media, and (d) media that integrate local cultural elements have the potential to increase student engagement and understanding. However, the study also found limitations in the development of media that support low-achieving students, the integration of technology into representation learning, and long-term research on the impact of learning interventions. The main implication is the need for a more integrated and technology-based approach to improve representation competence across different levels of students. As a novel contribution, this study recommends the development of Android-based applications for physics representation training, testing the effectiveness of local culture-based media, long-term impact research, and evaluation of user experience and feedback to strengthen future learning designs.

Keywords: representation competence, increased representational competence, next effort, literature review.

▪ INTRODUCTION

Representation competence has an essential role in university science education, especially physics. In today's rapid technological advancement and globalization era, representational competence is necessary for understanding and addressing complex scientific and technological challenges (Crawford et al., 2020). Representation competence in physics is essential because it is the primary means of presenting physics concepts, theories, and experimental findings clearly and accurately (Munfaridah et al., 2021). With representation competence, physics concepts can be understood and mastered more deeply. Representation is also essential in communicating complex ideas and facilitating a better understanding of natural phenomena (Hegarty & Kozhevnikov, 1999; Van Heuvelen & Zou, 2001). In addition, representational competence is integral in facilitating interdisciplinary collaboration, which is increasingly relevant in global research and industry (Chen & Gladding, 2014; van Garderen & Montague, 2003).

Research shows that effective use of representations can significantly improve student learning outcomes, such as conceptual understanding, problem-solving skills, and critical thinking (Klein et al., 2018; Maries & Singh, 2018; McPadden & Brewe, 2017; Podolefsky & Finkelstein, 2006; Rosengrant et al., 2009; Sutopo & Waldrip, 2014; Von Korff & Rebello, 2012). However, there is still a gap in how representations are used in teaching and understood by students, which often results in gaps in understanding and

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application. For example, teachers usually teach physics concepts using mathematical notation, which is complicated and difficult for some students to understand, so students have difficulty connecting mathematical symbols with physical phenomena in the real world (Lindenfeld, 2002). In addition, students also have difficulty in representing various forms of representation and translating existing representations (Anastasiadou & Gagatsis, 2017; Bollen et al., 2017; De Cock, 2012; Maries et al., 2017; Rane, 2017; Savinainen et al., 2007).

Various efforts have been made to improve students' representation competence. Some researchers use specific learning models in the learning process in the classroom (Fatmaryanti et al., 2018; Guidugli et al., 2005; McPadden & Brewe, 2017; Struck & Yerrick, 2010). Various approaches to learning have also been taken, such as assigning tasks that exercise representational competence (Scheid et al., 2019), learning using multiple representations (Bahtaji, 2020; Kohl & Finkelstein, 2006), and the use of scaffolding in learning (Maries et al., 2017). Learning media is also used to improve students' representation competence. Some researchers develop teaching media in the form of learning modules (Hill et al., 2015), haptic technology (Magana & Balachandran, 2017), computer-based learning media (Adlina & Supahar, 2019; M. G. Saputra & Ariswan, 2019; Yadiannur & Supahar, 2017), and computer-based modelling activities (Araujo et al., 2008). In addition, some researchers collaborate with local culture as a learning medium (Damayanti & Kuswanto, 2021; Husna & Kuswanto, 2018; Kurniawan & Kuswanto, 2021; Liliarti & Kuswanto, 2018; Maghfiroh & Kuswanto, 2022; Permata Sari et al., 2020; Priyadi & Kuswanto, 2023; Rahayu & Kuswanto, 2021; Raras & Kuswanto, 2019; M. R. D. Saputra & Kuswanto, 2019; Warsono et al., 2020).

While these efforts have yielded some positive results, there are still some challenges to be overcome and potential that can be explored to continue improving the effectiveness of physics learning. For example, there is a need for a systematic review that consolidates the efforts made and evaluates the integration of technology and cultural context. This article review aims to fill this gap by summarizing existing studies on improving representational competence in physics education and identifying future research directions. By analyzing past findings and exploring opportunities for innovation, this article seeks to contribute to the global discourse on optimizing physics education and preparing students to meet the demands of a rapidly changing world.

▪ METHOD

Research Design

This research study used the Systematic Literature Review (SLR) method adapted from Petticrew and Roberts' systematic review practical guidelines. The systematic review process is structured and thorough, involving the selection, search, identification, evaluation, and synthesis of all research related to a specific topic. (Petticrew, 2008). A systematic and organized approach involves several sequential stages, including defining research questions, setting eligibility criteria, screening articles, critically evaluating them, conducting an in-depth review, and sharing the findings, as shown in Figure 1.

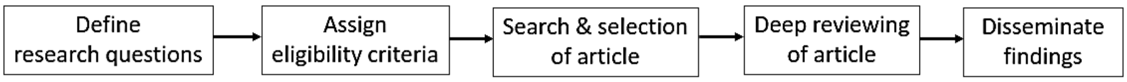

Figure 1. Systematic review procedures

Research Strategy

The research questions of this study can be written as follows: i) How can learning approaches improve representation competence? ii) How does the learning model affect the improvement of representation competence? iii) How effective is using learning media to improve representation competence? and iv) How can media with local cultural wisdom improve representation competence? After determining the research questions, the eligibility criteria were established, which were used to determine the eligibility of the articles reviewed. Articles were considered eligible and relevant if they fulfilled the following inclusion criteria: i) The publication results were published from 2000 - 2023; ii) The publication results from concern research related to efforts to improve representation competence; iii) The publication results are in the form of scientific articles; iv) The scientific articles are included in the quartile criteria (quartile rank 1 to 4) provided by https://www.scimagojr.com/.

Articles relevant to the study were collected by searching the Publish or Perish (PoP) database on the Scopus and Google Scholar websites. PoP searches were conducted for the period 2000 - 2023 with a combination of keywords "improve," "representation competence," "representation skill," "representation ability," and "physics." One search uses two to three keywords to make the results more specific. The article review's search and selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method (Liberati et al., 2009; Moher et al., 2009), as shown in Figure 2.

The search results obtained 1723 research articles in the last 23 years, namely 2000-2023. A total of 283 articles were removed due to duplication. The titles and abstracts of the 1,440 articles were screened to align with the research objectives. Fifty-two articles were thoroughly evaluated and assessed based on the predetermined inclusion criteria. Finally, 26 articles met the criteria of being Scopus-indexed international articles and were reviewed in depth. Articles were analyzed based on the following aspects: i) research objectives, research questions, and information about participants; ii) information about the research context; iii) how the effort was implemented; iv) methods used; and v) findings. The analyzed findings are next under the main themes formulated as questions (Table 1), corresponding to the 26 studies.

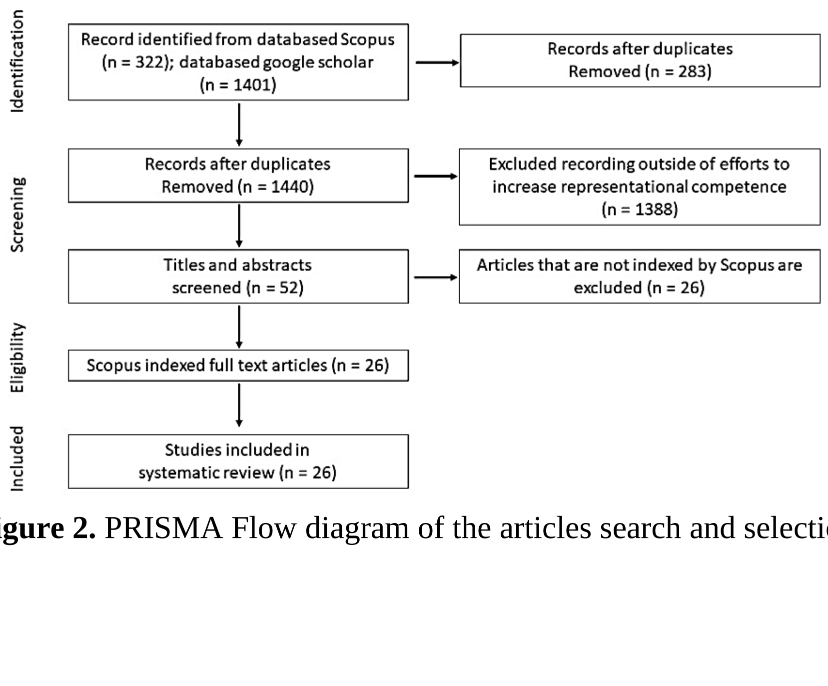

Figure 2. PRISMA Flow diagram of the articles search and selection

Inclusion and Exclusion Criteria

The population of this study includes all studies on efforts to improve representation competence in physics learning. Samples were carefully selected based on predetermined inclusion criteria, which are described in Table 1 below.

Table 1. Inclusion criteria

Inclusion criteria	Reason
The publication results were published from 2000 - 2023	This period was chosen to ensure that the data analyzed reflects the most current findings and approaches on representation.
The publication results from concern research related to efforts to improve representation competence	This research focuses on identifying efforts that have been made to improve students' representation competence in physics learning.
The publication results are in the form of scientific articles	This criterion is used to ensure that the literature reviewed has scientific credibility, relevance and validity in accordance with academic standards.
The scientific articles are included in the quartile criteria (quartile rank 1 to 4) provided by https://www.scimagojr.com/	SCOPUS indexed journals have high quality and accuracy standards in the publication process, including rigorous peer review.

Articles that did not meet the inclusion criteria were included in the exclusion criteria, namely (1) articles published other than the range of 2000 - 2024; (2) articles that were not relevant to the topic of efforts to improve representation competence in physics learning; (3) not a scientific article; (4) articles not indexed by SCOPUS.

Data Analysis

A descriptive qualitative data analysis approach was used to interpret the selected research results. The analysis process was conducted through four main stages. First, each article was read and understood thoroughly to gain an in-depth understanding of the findings and their relevance to the research. Second, the main findings from each study were summarized, focusing on the efforts that had been made to improve students' representational competence. Third, the findings were compared to identify the most common errors, trends or gaps between the studies. Finally, the researcher draws a comprehensive conclusion based on the synthesis of findings, which includes identifying areas that require further research and potential practical applications in education.

▪ RESULT AND DISSCUSSION

This study reviewed 26 articles (appendix 1) that had been selected using the PRISMA technique. The research examined efforts to improve representation competence. The articles were analyzed based on the following aspects: (a) research objectives, research questions, and information about participants; (b) information about the research context; (c) how the efforts were conceptualized; (d) methods used; and (e) findings. The analyzed findings are next under the main themes formulated as questions (Table 2), corresponding to the 26 studies.

Table 2. Themes of reviewed articles

Theme	Literature
How can learning approaches improve representation competence?	Bahtaji (2020) Guidugli et al. (2005) Kohl & Finkelstein (2006) Maries et al. (2017) Scheid et al. (2019) Volkwyn et al. (2020)
How does the learning model affect the improvement of representation competence?	Fatmaryanti et al. (2018) McPadden & Brewe (2017) Struck & Yerrick (2010)
How effective is using learning media to improve representation competence?	Adlina & Supahar (2019) Araujo et al. (2008) Hill et al. (2015) Magana & Balachandran (2017) M. G. Saputra & Ariswan (2019) Yadiannur & Supahar (2017)
How can media with local cultural wisdom improve representation competence?	Damayanti & Kuswanto (2021) Husna & Kuswanto (2018) Kurniawan & Kuswanto (2021) Liliarti & Kuswanto (2018) Maghfiroh & Kuswanto (2022) Permata Sari et al. (2020) Priyadi & Kuswanto (2023) Rahayu & Kuswanto (2021) Raras & Kuswanto (2019) M. R. D. Saputra & Kuswanto (2019) Warsono et al. (2020)

How Can Learning Approaches Improve Representation Competence?

Bahtaji (2020) examined the effect of a graphing intervention on students' graph representation skills and understanding of physics concepts (Bahtaji, 2020). This study involved three classes of first-year introductory physics students, each receiving a different intervention. The first class (n = 39) was shown graphs during teaching, the second (n = 34) learned graph construction and extraction, and the third (n = 34) practiced making and interpreting graphs. A concept test and a graphing skills test, validated by two lecturers, were given before and after the interventions to measure their impact. The concept test included 50 multiple-choice questions on force and motion, while the graphing skills test had five items requiring students to answer questions and create graphs from data. A rubric was used to rate students' graphs as high- or low-level. The results showed that all interventions improved concept understanding, while the intervention focusing on creating and interpreting graphs also enhanced graphing skills. Students learned to identify variables and symbols by constructing graphs, becoming more familiar with graphical representations. This process helped them form mental models, aiding later interpretation and understanding of graphs.

Guidugli et al. (2005) investigated the effectiveness of active learning strategies versus traditional learning in enhancing students' understanding of kinematics concepts and their graphical representations (Guidugli et al., 2005). This study was conducted with grade 10 students in a high school in Argentina and involved three physics teachers. One of the three high school teachers was a newly graduated physics teacher; another was a physics graduate student; and the third had more than 25 years of teaching experience and held a permanent teaching position at the school. The third teacher was unsure of the effectiveness of the teaching strategy chosen by the group and eventually decided to follow his traditional approach while still participating as a member of the teaching group. The TUK-K was used to test the effectiveness of the active learning strategy. The test was conducted before and after learning with active learning strategies. The results showed that Grade 10 students who participated in active learning understood basic kinematics concepts and graphical representations satisfactorily. The data also showed active learning is more effective in low-tech local education than traditional learning approaches.

Kohl and Finkelstein (2006) studied how the learning environment affects students' use of representations (Kohl & Finkelstein, 2006). They observed 600 students across three classes, two experimental and one traditional, analyzing lectures, exams, and homework for representation types (verbal, mathematical, graphical, pictorial, and physical). Two researchers conducted the analysis, assessing the average type of representation used in each lecture. The study found that while course content was similar, lecturers used different representation methods, influencing students' use of these forms. Exam questions in the experimental classes featured more representations than those in the traditional class, though only a few required multiple representations. In homework, the experimental class used more verbal representations across eight assignments, while the conventional class used more pictorial representations in fifteen assignments. This study indicates that a diverse learning environment can enhance students’ skills in using various representations, supporting their problem-solving abilities.

Maries et al. (2017) examined students' challenges translating mathematical and graphical representations in an electrostatics problem. They analyzed how varying levels of scaffolding influence the consistency of students' representations (Maries et al., 2017). Two types of scaffolding have been developed, namely scaffolding level 1 (SL1) and scaffolding type 2 (SL2). In SL1, students are instructed to draw the electric field for each region separately before sketching it for the given problem situation. This scaffolding is intended to guide students in reflecting on the behavior of the electric field in each area separately rather than considering all regions simultaneously. In SL2, students received SL1 and were instructed to assess the electric field at each region's beginning, middle, and end before sketching it within that region. The results showed that adding instructions in SL2 erased the benefits obtained by students from SL1. Meanwhile, SL1 is effective in helping students understand the differences, such as the electric field in each area, which impacts the consistency of student representations.

Scheid et al. (2019) researched to improve learners' representation competence with representation activity tasks related to experiments (Scheid et al. 2019). This study involved 342 students who were split into a control group (CG, N = 167) and a treatment group (TG, N = 175). The study focused on geometric optics at the junior high school level. An expert group of physics teachers, including those involved in the study, reviewed and validated the intervention and learning materials. Each teacher received the finalized materials and a schedule for each class session and was individually briefed on implementing the lessons for the control group (CG) and the treatment group (TG). An observer attended some lessons to ensure both groups adhered to the planned intervention strategy. The study used a non-equivalent comparison-group design with three assessments: a pre-test in week 1, a post-test in week 4, and a follow-up test in week 10. The CG worked with conventional tasks where relationships between representations were implicit, while the TG engaged with specific tasks (RATs) to improve representational coherence. These tasks included multiple representations and required students to develop coherent connections, such as translating, linking, comparing, complementing, correcting, and adapting representations. The same teacher instructed both CG and TG classes. Results revealed a significant and practically meaningful improvement in students' representational coherence ability, with positive effects of RATs persisting six weeks after the intervention.

Research conducted by Volkwyn et al. (2020) used a social semiotics approach in the teaching and learning undergraduate physics (Volkwyn et al., 2020). The researchers propose that representational competence for some areas of science can be characterized as the ability to interpret and produce disciplinarily accepted representations of real-world phenomena and relate them to scientific concepts. This characterization was applied by conducting a social semiotics audit for the physics area of 1-D kinematics and generating three open-ended tasks to help students develop representational competence on this topic. An authentic task example is given, and its potential effectiveness is demonstrated through empirical evidence. The research found that the tasks can develop and practice representational competence, as students can interpret and produce disciplinarily accepted representations of real-world phenomena and relate them to formalized scientific concepts. The study's results indicate that the social semiotics approach can assist teachers in helping students build and refine their representational skills across different semiotic systems in various areas of physics and science education. The research findings have implications for undergraduate physics teaching and learning and may offer broader lessons for developing representational competence in other areas of science.

The research findings synthesized in this section provide evidence that different learning approaches positively impact students' representational competence in physics concepts. Although the evidence from this synthesis shows that learning approaches support specific representational competencies (graphical, verbal, mathematical, pictorial), no direct evidence indicates that one approach is superior to another for enhancing physics-related representational skills. Instead, various learning approaches may be suited to different objectives and depend on students' previous experience with other types of representations.

How Does the Learning Model Affect the Improvement of Representation Competence?

Fatmaryanti et al. (2018) developed a learning model to enhance students' mathematical modeling skills by using the Guided Inquiry Model with Multi Representation (GIMuR), an inquiry-based approach with multi-representations (Fatmaryanti et al., 2018). GIMuR comprises five phases: Organization and Orientation, Sequence and Hypothesis, Investigation, Representation, and Evaluation and Reflection. The study involved 62 twelfth-grade students in Purworejo, Indonesia, divided into a control group (N=32) and an experimental group (N=30). Data was gathered through tests, observations, and interviews. A test with 15 multiple-choice questions assessed the effectiveness of GIMuR in improving students' modeling skills on magnetism concepts like the magnetic force on a moving charge and a current-carrying wire in a magnetic field. Using a checklist, two observers rated teacher and student activities during each GIMuR phase. Interviews with 18 students from the experimental group explored their understanding of magnetic force concepts. Findings showed that GIMuR significantly improved students' modeling skills compared to traditional methods, with both teacher and student activities rated positively. The Sequence phase helped students form hypotheses, and the Representation phase reinforced modeling skills through diverse representations. Interviews suggested that reviewing vector basics and guiding students with sketches and formulas in problem-solving would further support their learning. Using multiple representations in inquiry-based learning helps students explore concepts and enhances their mathematical modeling skills.

McPadden and Brewe (2017) investigated how Modeling Instruction (MI) influences students' ability to choose and use different representations in physics (McPadden & Brewe, 2017). They conducted a Problem Solving and Representation Use Survey (PSRUS) with 25 questions covering mechanics and electromagnetism topics. Students were given a list of 15 representations, such as graphs, equations, motion maps, force diagrams, and circuit diagrams. They were asked to select representations they would use to solve each question. The survey results helped identify which representations were emphasized in MI courses. The survey was administered before and after MI-EM (electromagnetism) instruction. Among the 58 students in the MI-EM course, 30 had previously taken MI for mechanics (MI-Mech), while 28 were new to MI. Findings showed that students who had taken MI-Mech consistently used a wide range of representations. In contrast, students new to MI showed significant growth in their representation use across the semester, highlighting the impact of MI on representational skills.

Struck & Yerrick (2010) compared the effectiveness of microcomputer-based laboratories (MBLs) and Digital Video Analysis (DVA) in improving students' understanding of graphs (Struck & Yerrick, 2010). The study at Williamston High School involved students using both methods to investigate the motion of one-dimensional objects. Half of the students used MBLs first, followed by DVA, while the other half used DVA first, followed by MBLs. Students completed distance-time (d-t), velocity-time (v-t), and acceleration-time (a-t) graphs before, after using one method, and after using both methods. The results showed that using both DVA and MBLs together improved students' graphing skills, with some students making more significant progress in creating v-t and a-t graphs after using DVA. For a week, students learned to design experiments, observe motion, and create graphs using both methods. Self-assessments showed that students gained confidence in their graphing skills across all scenarios. However, the study lacked student feedback on how DVA and MBLs work for different types of learners, which could provide helpful insights for addressing the needs of diverse students.

The three studies' findings reveal that different learning models can improve students' representation competence. This increase in representation competence is due to encouraging students to actively interact with other students, allowing them to convey their ideas and understand other people's points of view, which enriches their understanding of the material. In addition, using learning models that allow students to create experiments and observe directly makes them more confident.

How Effective is Using Learning Media to Improve Representation Competence?

Adlina & Supahar (2019) researched developing an example application of android-assisted kinematics questions to improve the physics representation competence of high school students (Adlina & Supahar, 2019). This study is developmental research involving 67 high school students in grade XI in one of the schools in Yogyakarta. Thirty-three students were in the experimental class, and 34 were in the control class. Before and after learning to use this application, students were asked to fill out a pre-test and post-test to measure the mathematical representation competence of physics students. Data analysis showed increased mathematical representation competence of students learning physics and had greater effectiveness.

Research conducted by Araujo et al. (2008) aimed to see the performance of physics students using computational modelling activities to improve the interpretation of kinematics graphs (Araujo et al., 2008). This study involved 52 first-year physics students from a university in Brazil who were randomly assigned to either an experimental or a control group. The experimental group participated in weekly sessions in a computer lab for four weeks, while the control group did not engage in any additional classroom activities. All participants had previously studied kinematics and continued with their regular physics classes on other topics throughout the experiment. Thus, the computational modelling activities served as a supplement to their traditional lessons. The experimental group undertook two types of activities: exploratory and expressive. In exploratory activities, students used the Modellus models created by the researchers to observe, analyze, and understand the connections between the mathematical aspects of the models and the physical phenomena under study. They interacted with the models by adjusting initial values or parameters to address specific questions or challenges. In expressive activities, students developed their models from scratch, including constructing the mathematical framework and representing the results. They received qualitative and quantitative information and were asked questions to guide them in creating models that accurately depicted the phenomenon being studied. Students could choose their approach, interact with the model extensively, and modify it as needed. The treatment involved weekly 2-hour and 15-minute sessions in a computer lab, where the experimental group engaged in a series of modelling activities designed to address challenges and meet learning objectives. Students worked individually or in pairs, and occasional interactions with nearby classmates were daily. The learning materials included the Modellus model, a printed guide with instructions for exploring and building the model, and questions to help complete the tasks. The results indicated a statistically significant improvement in the experimental group's performance compared to the control group, which only received conventional instruction. Students' understanding of mathematical concepts, perception of relationships, and motivation for learning contributed significantly to these positive outcomes.

Hill et al. (2015) conducted a study to develop, implement, and evaluate the use of an online learning module (OLM) consisting of several representations (Hill et al., 2015). The study involved 400 first-year undergraduate physics students randomly assigned to either a concept-based online learning module (OLM) or a representation-based OLM. Participants completed a pre-test and post-test on conceptual understanding using the Force and Motion Concept Evaluation (FMCE) and a representation survey using the

Representational Fluency Survey (RFS) before and after using the module. Data analysis revealed that the online pre-course learning module significantly improved conceptual reasoning and representational competence.

The research conducted by Magana & Balachandran (2017) aimed to identify new forms of 'direct' teaching that can result in representational competence and conceptual acquisition (Magana & Balachandran, 2017). This study assessed whether visuohaptic simulations influence students' representations of electromagnetics-related concepts. It involved nine undergraduate students from science, technology, or engineering disciplines. Data was gathered using the think-aloud method during interactions with the visuohaptic simulation, which was structured into three phases: (1) a prediction phase to gauge students' prior understanding, (2) a minimal visual haptic phase with just enough visual cues to observe how students interpret and use touch to represent their understanding, and (3) a visual haptic enhancement phase to determine if students affirmed or revised their existing or new knowledge. The study demonstrated that students accurately identified and represented forces around particle charges, lines, and rings in all three phases. Additionally, some students effectively described the field's three-dimensional nature in two stages involving tactile modes, with point charges being the most challenging. The findings also indicate that manipulable elements and multi-modal representations facilitated by visuohaptic simulations can enhance students' representational competence.

M. G. Saputra & Ariswan (2019) developed a problem-based learning interactive CD on simple harmonic material to improve diagrammatic and mathematical representation competencies (M. G. Saputra & Ariswan, 2019). This study is development research with a 4D model involving 64 students in one high school in Yogyakarta. Thirty-two students were in the experimental class, and 32 were in the control class. Changes in representation competence of both classes were measured using pre-test and post-test. Data analysis revealed that using interactive learning media, such as interactive CDs, led to an effective and efficient learning process, evidenced by improvements in students' mathematical representation skills and diagramming abilities.

Research conducted by Yadiannur & Supahar (2017) aims to improve students' representation competence by developing mobile learning-based applications on electrical circuits for high school students (Yadiannur & Supahar, 2017). This study is a development research project using the 4D model conducted at a high school in Samarinda, East Kalimantan. It involved nine experts and included 35 twelfth-grade students for the preliminary test and 74 twelfth-grade students for the field test. The research data were collected through non-test and test instruments. Non-test instruments consisted of product feasibility instruments, material feasibility instruments, and preliminary field trial instruments. The test instrument consists of pre-test and post-test data to measure students' electrical circuit interpretation skills. In the field test, students were divided into two classes, namely the experimental class and the control class. Before and after learning to use this application, students were asked to complete a pre-test and post-test to see changes in student representation competence. The results of data analysis show that the developed application can improve students' representation competence in electrical circuits.

Summarising the research findings reviewed in this section, it becomes clear that using learning media has proven effective in improving students' representational competence by providing various visual tools that help them understand concepts more concretely. Media such as images, videos, and interactive simulations allow students to visualize complex information and relate it to real-world situations, enhancing their understanding. However, some drawbacks need to be considered when using learning media. One is accessibility and infrastructure, which may be limited, especially in less developed areas. Not all students have equal access to technology or a stable internet connection, which may hinder the effective use of such media. In addition, distractions during the use of learning media can also reduce effectiveness. Therefore, while learning media can be a helpful tool to improve representational competence, it is crucial to be mindful of the challenges and drawbacks that may arise and seek a balanced approach between the use of media and conventional learning methods.

How can Media with Local Cultural Wisdom Improve Representation Competence?

Damayanti & Kuswanto (2021) conducted a study on the effectiveness of using physics comics based on local knowledge of Android-based marble games on verbal representation (Damayanti & Kuswanto, 2021). This research employed a pseudo-experimental design with a pretest-posttest control group. The sample comprised two classes, a control and an experimental group, with 35 students selected through cluster random sampling. Data analysis revealed that developing physics comics based on local wisdom, specifically Android-based marble games, positively impacts students' verbal representation in physics learning. In other words, the developed comics effectively enhance students' verbal representation competence.

Similar research was also conducted by Permata Sari et al. (2020), who developed physics comic media based on the local wisdom of engklek game in learning impulse and momentum material in high school to improve students' mathematical representation (Permata Sari et al., 2020). Thirty students participated in the preliminary study, and 60 participated in the research activities, divided into experimental and control groups. Data on students' mathematical representation competence were collected through tests given before and after learning activities using the developed comic media. The results of data analysis showed that the Physics comic based on local wisdom assisted by Android can improve the mathematical representation of high school students.

Rahayu & Kuswanto (2021) also developed comics but used an android-based carom game integrated with the discovery learning model to improve mathematical representation competence (Rahayu & Kuswanto, 2021). Participants were selected using the cluster random sampling technique, including 64 high school students divided into control and experimental groups. The control group used only PowerPoint for instruction, whereas the experimental group utilized Android-based Carom game comics integrated with the Discovery Learning model. The effectiveness of the comics was evaluated through pre-tests and post-tests administered with a two-session interval. The results showed that the experimental group improved mathematical representation competence more than the control group. The Android-based Carom game comic and the Discovery Learning model proved an effective alternative learning tool for enhancing mathematical representation competence.

Research conducted by Priyadi & Kuswanto (2023) also examines the development of comics, namely the android-based Gajah Mungkur Dam comic, to improve mathematical representation competence (Priyadi & Kuswanto, 2023). The study included 262 high school students for empirical testing, 36 for limited trials, and 72 for field trials. The developed comic media comprised an introduction, comic content on work and energy, an instruction manual, a learning video, and a discussion column. Tests were conducted before and after the learning sessions to evaluate the effectiveness of the comics. The analysis revealed a significant difference between the control and experimental groups. The comics developed effectively improve mathematical representation competence despite the small changes.

Maghfiroh & Kuswanto (2022) developed an android-based comic about the traditional game Bethink to improve vector representation competence (Maghfiroh & Kuswanto, 2022). This study involved four high schools in Sleman district with a total of 262 participants. The research instrument is a valid and reliable vector representation test question based on empirical tests. Tests were conducted before and after the learning activities to evaluate the comics' effectiveness. The analysis showed that the comics used effectively improved the competence of vector representation.

Liliarti & Kuswanto (2018) developed android-based learning media with local cultural content in the form of othok-othok toy ships to improve the competence of diagram representation (Liliarti & Kuswanto, 2018). This study involved 60 high school students divided into experimental and control groups. Experts initially validated the essay-type test instrument and then empirically tested it on 100 other students who had previously studied Newton's Law, Archimedes' principle, and convective heat transfer. The effectiveness of the learning media was assessed through pre-test and post-test scores. The results indicated that the Android-based learning media, featuring local content such as othok-othok toy ships, effectively improved students' diagram representation competence. This media can be utilized as a resource for physics instruction inside and outside the classroom.

Similar research was also conducted by M. R. D. Saputra & Kuswanto (2019), who developed Physics Mobile Learning (PML) with the Android theme HomboBatu to improve students' diagram representation competence (M. R. D. Saputra & Kuswanto, 2019). This research is experimental research with a pretest-posttest control group design. The selection of sampling techniques using cluster random sampling. The research subjects were X-grade high school students in one of the schools in Yogyakarta. Thirty-two students were in a control class with PowerPoint media learning treatment, and 22 were in an experimental class with Android-assisted PML learning treatment for the HomboBatu theme. The test instrument consisted of pre-test and post-test. The results showed that learning with Android-assisted PML on the theme of HomboBatu was more effective in improving the competence of diagram representation than learning with PowerPoint. Students or teachers can use Physics Mobile Learning to study Indonesian culture (Nias) both for its learning media and for learning experiences that train diagrammatic representation competence.

Husna & Kuswanto (2018) also developed PML based on the local wisdom of waterwheels to improve the competence of vector representation and diagrams (Husna & Kuswanto, 2018). This study involved 25 students in the control and 25 students in the experimental classes. Tests were given before and after learning to use PML, and the results were compared with those of the control class to determine the impact of using PML. The results showed that the learning media can improve students' competence in vector representation and diagram representation.

Research conducted by Raras & Kuswanto (2019) aims to improve the competence of graphic and vector representations through the traditional android-based Jemparingan game media on parabolic motion vector sub-material (Raras & Kuswanto, 2019). Field trials were conducted with 61 students, including 29 in the control and 31 in the experimental classes. The results revealed differences between the experimental class, which used the developed media, and the control class, which used PowerPoint. The developed media positively influenced improvements in graphic and vector representation competence.

Kurniawan & Kuswanto (2021) created learning media based on the local wisdom of the becak, supported by Android, to enhance students' mathematical representation competence (Kurniawan & Kuswanto, 2021). This study took place at a high school in Yogyakarta and involved 69 students, split into a control group of 35 students and an experimental group of 34 students. Data were gathered through written pre-tests and post-tests, with the results analyzed using gain score analysis. The findings indicated that the locally-based pedicab media, supported by Android (CAKA), is effective as a learning tool, enhancing students' mathematical representation competence.

In line with the above research, research conducted by Warsono et al. (2020) on Multimedia Learning Modules (MLM) based on local wisdom aims to improve students' diagram representation (Warsono et al., 2020). The study employed a pretest-posttest control group design. The research instruments included both tests and non-tests. The test component consisted of five items based on indicators of diagrammatic representation, such as drawing diagrams and their components and performing mathematical calculations related to the diagram. The non-test component was a questionnaire related to the test instruments. The results demonstrated that the developed MLM effectively enhanced students' diagrammatic representation in physics learning activities.

Based on the research findings in this section, it can be concluded that local cultural wisdom can be a powerful medium for improving students' representational competence as it includes values, traditions, and practices that are rich in symbols and visual representations. Using local cultural elements in learning can help students more deeply understand abstract concepts by relating them to relevant contexts in their own culture. It deepens their understanding of the subject matter and reinforces their cultural identity. However, the drawback of using local cultural creativity in learning media lies in limiting universally acceptable representations. Sometimes, local cultural symbols or concepts may be complicated for students from different cultural backgrounds to understand, which may reduce the effectiveness of such media in improving overall representation competence. Therefore, a careful approach to selecting and integrating local cultural elements into learning media is needed to ensure that various students can widely and effectively receive the messages.

Synthesis and Gaps in The Literature

In synthesizing the existing literature on improving representation competence, the importance of representation in physics learning is apparent. Representations help students to understand physics concepts that are often abstract and complex. Students can visualize physical phenomena and their mathematical relationships through representations such as pictures, graphs, diagrams, and mathematical symbols. Representations also assist students in communicating their ideas more clearly and precisely. Efforts to improve representation competence are certainly needed. Overall, the results of the review show that the use of various learning approaches can improve students' representation competence (Bahtaji, 2020; Guidugli et al., 2005; Kohl & Finkelstein, 2006; Maries et al., 2017; Scheid et al., 2019; Volkwyn et al., 2020). Several other studies have shown that using different learning models can improve students' representational competence (Fatmaryanti et al., 2018; McPadden & Brewe, 2017; Struck & Yerrick, 2010). More recent research provides evidence that the use of learning media can improve students' representation competence (Adlina & Supahar, 2019; Araujo et al., 2008; Hill et al., 2015; Magana & Balachandran, 2017; M. G. Saputra & Ariswan, 2019; Yadiannur & Supahar, 2017), including when the learning media is associated with local wisdom (Damayanti & Kuswanto, 2021; Husna & Kuswanto, 2018; Kurniawan & Kuswanto, 2021; Liliarti & Kuswanto, 2018; Maghfiroh & Kuswanto, 2022; Permata Sari et al., 2020; Priyadi & Kuswanto, 2023; Rahayu & Kuswanto, 2021; Raras & Kuswanto, 2019; M. R. D. Saputra & Kuswanto, 2019; Warsono et al., 2020).

The results of this study can be summarized as follows: Good representation competence significantly helps students in solving problems and deepening their understanding of concepts (Sutopo & Waldrip, 2014; Umrotul et al., 2022). To address the gaps identified in the literature, a research agenda is proposed to improve students' representation competence in physics. One of the most common difficulties students face when using multiple representations (MR) is representational fluency, which involves switching between different forms of representation (Chiou & Anderson, 2010; Ibrahim & Rebello, 2013; Umrotul et al., 2022). Various teaching approaches and learning models can be applied in the classroom to improve this competency (Bahtaji, 2020; Guidugli et al., 2005). In addition, the learning environment plays an important role; what students experience, see, and feel contributes to their understanding of certain phenomena and concepts (Jufriadi et al., 2023; Kohl & Finkelstein, 2006; Kusairi et al., 2019). Providing scaffolding assistance has also been shown to facilitate students in overcoming representation-related challenges (Maries et al., 2017).

The literature review also highlighted some gaps that warrant further investigation. In particular, there is no evidence regarding which form or combination of representations is most effective for specific groups of students, such as low-achieving students. Furthermore, no studies were found that explored (a) specific problem exercises designed to train representational competence, (b) evaluation of the effectiveness of technology in improving this competence and the factors that influence it, or (c) the long-term impact of interventions designed to improve representational competence. Based on the identified literature gaps, we propose the following research agenda to improve representation competence in physics for university students.

Future Research Agenda

Continuous research and innovation are essential to improve students' representational competence. This section outlines four key considerations for improving this competence, specifically in the context of kinematics of straight motion. While recognizing the value of previous efforts in physics education, the proposed approach aims to provide a more effective solution for developing representational skills, particularly in understanding kinematics concepts.

First, Android apps should be developed specifically to train students' representational competencies. The app can include various exercises, such as visualization tasks, graph interpretation, concept mapping, and problem-solving activities, to create an interactive and engaging learning experience. The ultimate goal is to help students improve their ability to work with various representations.

Second, the effectiveness of the app should be evaluated through rigorous research. A randomized control experiment can compare a group of students using an app for representation practice with a control group following conventional learning methods. By conducting pre- and post-intervention assessments, the impact of the app on improving representation competence can be measured.

Third, long-term studies are essential to understand the app's sustained impact on students' representational competence. These studies can track students' progress over several semesters or academic years, analyzing the factors that influence the app's long-term effectiveness and its role in driving continuous improvement.

Finally, user feedback is critical to improving the app. Input from students and teachers can be collected through surveys, interviews, or focus groups to identify user challenges, improve app features, and ensure relevance and usability.

The implementation and study of this strategy is expected to address the existing research gap in the development of representation competence. Furthermore, this initiative offers an innovative solution in the form of an Android application specifically designed for representation training, which has the potential to change the way students learn and apply physics concepts.

▪ CONCLUSION

This review study has reviewed 26 articles related to improving representation competence. The results of the review study show that the difficulty that students often experience is to switch from one form of representation to another. Various efforts have been made to improve students' representation competence. However, these efforts evaluate the long-term impact of the interventions provided. In addition, some of the efforts that have been made have not integrated technology. Efforts that have integrated technology have not shown what factors affect its success. Based on the results of this study, four things need to be considered for future research to be better: the development of Android applications for representation training, evaluation of application effectiveness, long-term studies on the impact of the developed applications, and evaluation of user experience and feedback.

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