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Smart Learning Environments

REVIEW

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# Multimedia learning principles in different learning environments: a systematic review

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**Abstract**

Current literature mainly focused on one or two multimedia learning principles in traditional learning environments. Studies on multimedia learning principles in AR and VR environments are also limited. To reveal the current situation and gaps of the multimedia learning principles in different learning environments, it is necessary to extend their boundaries. Thus, further studies may directly affect the investment in VR and AR technologies and their integration into the learning process by teachers. The current study presented a systematic review of multimedia learning principles in different learning environments, including traditional, virtual reality and augmented reality. In this study, 136 journal articles were identified based on PRISMA guidelines and reviewed regarding multimedia learning principles, learning environments, measurements, subject matters, learning outcomes, research methodologies, education programs, education fields, and years of publication. The results indicate that (1) there is an increasing interest in multimedia learning principles; (2) undergraduate students have been the target participant group in the review studies; (3) only five studies tested one of the multimedia learning principles in the VR environment, but no studies have been conducted in the AR learning environment; (4) most studies preferred subjective measurements (e.g., mental effort, difficulty) or indirect objective measurements (e.g., learning outcomes, eye-tracking, study time); (5) subject matters from STEM fields often preferred in investigations; and (6) modality was the most studied multimedia learning principle in the reviewed articles, followed by redundancy, multimedia, signaling, coherence, segmenting, personalization, spatial contiguity, temporal contiguity, image, pre-training, and voice, respectively. The results were discussed in detail. Specific gaps in the literature were identified, and suggestions and implications were provided for further research.

**Keywords:** Multimedia learning, Multimedia learning principles, Learning environment, Augmented reality, Virtual reality, Systematic review

## Introduction

With the help of developing technologies, the learning process has become much more effective because of modern equipment and tools that facilitate learning and increase interactivity among students (Raja & Nagasubramani, 2018). For example, students can learn complex concepts in a controlled environment via augmented reality (AR) and virtual reality (VR) headsets, making learning immersive and experiential (UKAuthority, 2019).

The role of a learning environment has been expanded over time with the help of modern digital technologies and online resources (Vinales, 2015), as they have considerably changed the way students learn and teachers teach (Manzoor, 2016). The learning process can be improved when the learners' needs and learning styles are considered in a learning environment (Erden & Altun, 2006). Therefore, learning environments must be adequately flexible, and multimedia technologies must be carefully chosen for effective learning.

Multimedia can be described as presenting verbal and pictorial information simultaneously (Richter et al., 2016). When the instructional message is provided with both forms together, it is referred to as multimedia learning, which is also defined by Mayer (1997) as a process of learning containing both pictures (e.g., video or animation) and words (e.g., verbal or written text). The researchers have conducted many studies to examine the effect of multimedia in much research (Mayer, 2017; Wang et al., 2017; Weng et al., 2018). The number of studies exploring the specific effects has increased, especially after the 1990s (Li et al., 2019). Following the earlier findings, the Cognitive Theory of Multimedia Learning (CTML) was developed by Mayer (2009), describing the underlying processes in learners' minds during meaningful learning.

Mayer and colleagues contributed to formulating 12 design principles, initially validated using written text on paper and diagrams accompanying verbal or recorded audio demonstrations (Mayer et al., 1996; Moreno & Mayer, 1999, 2000; Mousavi et al., 1995). Nowadays, especially with the rapid development of multimedia technologies, these multimedia principles have been extended in diverse learning settings, such as computer-based learning environments (Kutbay & Akpinar, 2020; Park et al., 2015), web-based learning environments (Chen & Yang, 2020; Sung & Mayer, 2012), virtual learning environments (Kartiko et al., 2010; Parong & Mayer, 2018), or augmented learning environments (Küçük et al., 2016; Lai et al., 2019).

In addition to empirical studies testing and validating multimedia learning principles in different learning environments, many review and meta-analysis studies also provide valuable contributions to reveal the field's current state by focusing on various topics. For example, the recent systematic reviews focused mainly on the working memory (Anmarkrud et al., 2019), cognitive load (Mutlu-Bayraktar et al., 2019), eye tracking (Alemdag & Cagiltay, 2018), and trends and issues (Li et al., 2019). On the other hand, the meta-analyses were conducted more targeting the multimedia principles such as redundancy (Adesope & Nesbit, 2012), modality (Ginns, 2005), spatial contiguity (Schroeder & Cenkci, 2018), temporal contiguity (Ginns, 2006), segmenting (Rey et al., 2019), and signaling (Richter et al., 2016; Schneider et al., 2018) principles. Even though their results are crucial to guide future studies, most multimedia learning research in the reviews and meta-analysis has been conducted in traditional learning environments. The results of the current meta-analysis by Mutlu-Bayraktar et al. (2019) revealed that a conventional learning environment (93.62%) was preferred most often compared to AR (4.25%) and VR (2.13%) among 94 studies. Moreover, studies that test multimedia learning principles in AR and VR environments are limited (Akçayir & Akçayir, 2017; Selzer et al., 2019). To the best of our knowledge, no systematic review study has been conducted to examine all multimedia learning principles in different learning environments. In addition, investigating multimedia learning principles in AR and VR learning environments is very important for future research to reveal the current status and gaps of multimedia learning principles in different learning environments and expand their boundaries. For this reason, a systematic review is needed, investigating principles of multimedia learning by considering learning environments (i.e., virtual reality, augmented reality). The current study aims to reveal the current situation and gaps of the multimedia learning principles in different learning environments. This study presents the following research questions:

1. What are the general characteristics and specific design features of multimedia learning research used to investigate multimedia learning principles?
2. What learning environments (i.e., AR, VR, or traditional) are commonly preferred to test multimedia learning principles?
3. What are the measurements and subject matters commonly used in testing multimedia learning principles?
4. How does using multimedia learning principles affect students' learning in different learning environments?

## Background

### Learning environments

The learning environment consists of physical locations, contexts and cultures that students learn (Bakhshialiabad et al., 2015). It can also be defined as a complex and dynamic system where teachers implement specific strategies and use available resources to reach pre-determined learning goals (Wang & Kinuthia, 2004). The learning environment has an essential role in the learning process (Vinales, 2015) because it helps learners develop their skills, knowledge, attitude, and behavior (Ozerem & Akkoyunlu, 2015).

Even though the learning environment has been traditionally used as a synonym of a physical classroom, it has been changed with modern digital technologies, techniques, and strategies to provide more effective and efficient learning (Baeten et al., 2010). Integrating technology into the learning process is often referred to as technology-enhanced learning (Law et al., 2016). The concept of technology-enhanced learning has been named differently in the literature, such as computer-based learning, web-based learning, mobile learning, augmented reality-based, virtual reality-based (Chen & Yang, 2020; Cubillo et al., 2014; Hamilton et al., 2021; Moos & Azevedo, 2009). Many current technologies, including mobile devices, Web 2.0, AR, and VR, have been utilized increasingly in the learning process to improve the learning process by taking advantage of their unique features (Cubillo et al., 2014). For instance, AR and VR have been used in 96% of UK universities and 79% of UK colleges to provide good quality experiential learning for students (UKAuthority, 2019).

AR is used for enhancing the real world with virtual objects by presenting additional information without decreasing the authenticity of the physical world (Azuma, 1997). AR can help students to understand various complicated subjects such as chemical reactions that are difficult to observe in the real world easier (Akçayır et al., 2016). Besides, AR enables students to link real-life by displaying and controlling virtual elements over physical objects (Wu et al., 2018). For instance, AR allows students who have difficulty with geometry to experience and manipulate 3D geometric forms. With such features, AR as a learning environment positively contributes to the learning process by encouraging students to engage in learning activities (Akçayır & Akçayır, 2017; Di Serio et al., 2013; Garzón et al., 2019).

On the other hand, VR has been described as an artificial environment developed by software to make users think in a different atmosphere apart from the real world. VR as a learning environment provides a virtual space to reach learning outcomes by encouraging learners to discover freely within a safe and controlled environment (Ip & Li, 2015). Like AR, the activities and experiences in a virtual learning environment lead to better learning and, at the same time, motivate learners (Di Natale et al., 2020). Besides, VR can provide a safe learning experience by removing dangerous materials or any possible mistakes that can harm students (Abulrub et al., 2011). For example, experiments that may pose a danger to students can be performed without taking any risks, or magnitudes of gravity can be manipulated in a virtual lab to understand its effects. By considering such features, VR learning environments are more beneficial for learning when compared to traditional learning environments, including desktop computers and slideshows (Hamilton et al., 2021).

### Cognitive load theory

Cognitive load is considered an essential factor in the learning process. CL theory was developed initially by Sweller (1988) to examine mental processing limitations concerning learning. Then, it has been advanced by other researchers (Chandler & Sweller, 1991; Mousavi et al., 1995; Sweller et al., 1998). According to the CL theory, the elements making up the cognitive architecture of humans consist of long-term memory and working memory (Mousavi et al., 1995; Sweller, 2008). Moreover, the cognitive load emphasizes that the novel information can be accumulated in the long-term memory after first processed by the working memory (Sweller et al., 1998). However, acquiring new knowledge is more difficult when the working memory, which has limited capacity, is overloaded by information and processing demands (Greer et al., 2013). Therefore, the unnecessary loads in the working memory should be reduced when designing instructional material (Mutlu-Bayraktar et al., 2019).

The CL theory identifies three forms of cognitive load, such as intrinsic, extraneous, and germane cognitive load on the working memory in the learning process (Sweller et al., 1998). Intrinsic cognitive load is imposed by the complexity and difficulty of the information aimed to be learned by the learners. Some learning tasks may be more complicated than others, regardless of the instructional approach. For instance, solving an equation with three unknowns is more complex than a subtraction operation. Accordingly, the more difficult the learning task, the greater the intrinsic cognitive load is. Nevertheless, the difficulty of a learning task is a feature playing a role in determining the intrinsic cognitive load and the learners' prior knowledge (Sweller et al., 1998, 2011).

On the other hand, the extraneous cognitive load does not consider the complexity of a task but concerns how the learning material is presented. It results from inappropriate instructional design, such as explanation adequacy or instructional material integration (Mutlu-Bayraktar et al., 2019). Poorly designed instructional materials should be decreased as much as possible (Paas & Sweller, 2014). The third form of the cognitive load is germane, defined as the degree of the learners' mental effort in constructing schemas when relating information from long-term memory to new information. It can also be affected by other factors, such as the motivation or interest of the learner (Whelan, 2007). The remaining capacity from extraneous and intrinsic loads plays a role in whether the degree of the germane cognitive load increases or decreases (Paas & Sweller, 2014).

#### Cognitive theory and multimedia learning

Cognitive Theory of Multimedia Learning (CTML), developed by Mayer (2005), explains the process occurring in learners' minds during meaningful learning from multimedia instruction. It is built on three assumptions: the dual-channel, limited capacity and active processing (Mayer, 2005). According to the dual-channel assumption, there are two distinct channels to manage information: visual/pictorial and auditory/verbal. The visual/pictorial channel is through the eyes, including words displayed on a screen, whereas the auditory/verbal channel is through the ears (Mayer, 2009). Paivio (1991) with dual coding theory and Baddeley (1986) with working memory theory is also in line with the idea of separated information processing.

The limited capacity assumption assumes that each channel has a limited capacity to process information at any given moment, similar to the Cognitive Load Theory (Chandler & Sweller, 1991) and Working Memory (Baddeley, 1986). Miller (1956) proposes that most people can hold up to seven pieces of information in their working memory at a specific time. People with efficient metacognitive strategies may increase the range of managing their limited cognitive resources (Mayer, 2009). The third one is active processing, where the person actively joins in the learning process. This process consists of three steps. It starts with selecting words and pictures via sensors (i.e., ears, eyes). Then, the selected data (words and images) is organized into mental interpretations and integrated with the existing information from long-term memory (Mayer, 2009).

Since there is a limited capacity in working memory based on the assumption mentioned above, learning is hindered when the limit is exceeded (De Jong, 2010). That also leads to cognitive overload. The instructional designs should be constructed appropriately for individuals' cognitive processing to avoid overloading the memory demand and reduce the cognitive load. Mayer (2014) introduced twelve multimedia learning principles by categorizing them into three types of learner processing: extraneous processing, essential processing, and generative processing. These processing types resemble the intrinsic, extraneous, and germane cognitive load.

There are five principles to reduce extraneous cognitive load: Coherence, Signaling, Redundancy, Redundancy, and Temporal Contiguity principles. According to the coherence principle, the best learning from multimedia material occurs when interesting but irrelevant content is avoided since it does not help the learning process (Mayer & Jackson, 2005). It may prevent students from constructing mental models to represent the information. The signaling principle suggests that people learn better when the cues are added to the learning material to pay learners' attention to the essential part of the learning material (e.g., Van Gog, 2014). Highlightings, arrows, and other indicators can attract learners' interest. The redundancy principle recommends that people learn better when acquiring knowledge from animation with narration than animation with narration and on-screen text since their attention is distracted when presenting information with narration, animation and on-screen text (Sweller, 2005). The spatial contiguity principle concerns the actual space between presented words and pictures. It asserts that they should be physically close together for better learning (Mayer & Fiorella, 2014). Otherwise, the learner tries to find the related text and images to make connections, which causes the cognitive load. The temporal contiguity principle imposes to present correspondent narration and animation concurrently rather than sequentially (Mayer, 2009). In other words, the timing of the narration should be appropriate to play along with animations.

The following three principles for managing the intrinsic cognitive load are Segmenting, Pre-training, and Modality principles. Segmenting principle states that students can learn better while the learning material is served with smaller portions (Mayer & Pilegard, 2005). The principle also asserts that if the learner controls the speed of multimedia instruction, they will learn better. That is also called "user-paced". If the multimedia instruction is system-paced, that may lead to having difficulty comprehending fully and seeing the causal relationship between one step and the next. According to the pre-training principle, learning can be improved if the key concepts and main characteristics are provided before learning (Mayer, 2009). Learners may need time to mentally construct a causal model in multimedia instruction, especially when the content is complex. Pre-training helps manage such demands for essential processing by serving key elements and features. The modality principle claims that people learn better when the information is served as narration instead of on-screen text because two channels are used when the words are served as narration (Moreno & Mayer, 1999).

The remaining four principles help learners minimize the germane cognitive load, namely Multimedia, Personalization, Voice, and Image principles. Based on the multimedia principle, people learn more thoroughly when exposed to both words and images than words because they connect them mentally (Mayer, 2009). The words can be either printed or spoken, but not both simultaneously. The personalization principle indicates that having a more conversational style enhances learning than a formal style (Mayer et al., 2004). Thus, instructional designers should avoid using academic language as much as possible. It is asserted in the voice principle that "people learn better when narration is spoken in a human voice rather than in a machine voice" (Mayer, 2009, p. 242). Last but not least, the image principle states that adding speakers' pictures when presenting learning material does not mean that learning outcomes are improved. It is better to use relevant animations and visuals instead of displaying a talking head of the instructor.

## Methodology

### Search strategy

The systematic review reporting was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). It includes well-defined stages of a systematic review, such as describing the eligibility criteria, information sources, search strategies, study selection processes, and synthesis of results. Scopus, Web of Science (WoS), Education Resources Information Center (ERIC), ScienceDirect databases were used to retrieve the related research articles in

**Table 1** Keywords used with the "OR" boolean operator

| | | |
|---|---|---|
| "Multimedia learning principle" | "Redundancy principle" | "Modality principle" |
| "Principle of multimedia learning" | "Spatial contiguity principle" | "Multimedia principle" |
| "Cognitive theory of multimedia learning" | "Temporal contiguity principle" | "Personalization principle" |
| "Coherence principle" | "Segmenting principle" | "Voice principle" |
| "Signaling principle" | "Pre-training principle" | "Image principle" |

**Table 2** Inclusion and exclusion criteria

| Inclusion criteria | Exclusion criteria |
|---|---|
| 1. Articles should have been published in journals indexed by WoS, ERIC, Scopus, and ScienceDirect databases<br>2. Articles are peer-reviewed<br>3. Full-text available<br>4. Articles that use one of the principles of multimedia learning | 1. Conference proceedings, dissertations/thesis, and book chapters are not selected<br>2. Review, meta-analysis, or commentary articles are not selected<br>3. Articles that are not published in English |

this review. Scopus and WoS databases were selected due to their worldwide use and multidisciplinary nature (Zancanaro et al., 2015). ERIC and Science Direct mainly involve educational and technical literature. Therefore, they entirely cover application areas of multimedia learning principles. The keywords in Table 1 were used with the "OR" Boolean operator. Each multimedia learning principle was used as a keyword because some researchers prefer to use the name of the multimedia learning principle directly. While searching, there was no time limitation (the database holds articles dating from 1996 to 2020). However, the search was restricted to English journal articles that included full text. The latest search was conducted on 31 December 2020.

### Study selection process

The initial literature search resulted in 1259 papers from Scopus, Web of Science, ERIC, and ScienceDirect databases. These were downloaded to a computer as Microsoft Excel documents. First, 501 duplicated studies were detected and removed from the list. Second, the remaining 758 articles were screened and examined using their titles and abstracts to decide whether they met the inclusion and exclusion criteria validated by two experts (Table 2). Third, according to the criteria set, the full texts of the remaining 190 articles were critically assessed to ensure that all research questions were satisfactorily addressed. Fifty-four articles were eliminated during the evaluation process, and 136 papers were found to be relevant to the systematic review. Then, two other researchers (each has years of academic experience) reviewed and had an agreement on the whole elimination process. This literature search and review procedure is represented in Fig. 1.

### Data extraction and analysis

The articles selected for this review were analyzed concerning year, education program, research methodology, learning environment, multimedia learning principles, measurement, subject matter and field, and results. The year is the publication date in the journal, which is indicated in the article. Table 3 represents the education program obtained from the International Standard Classification of Education (ISCED, 2011). The

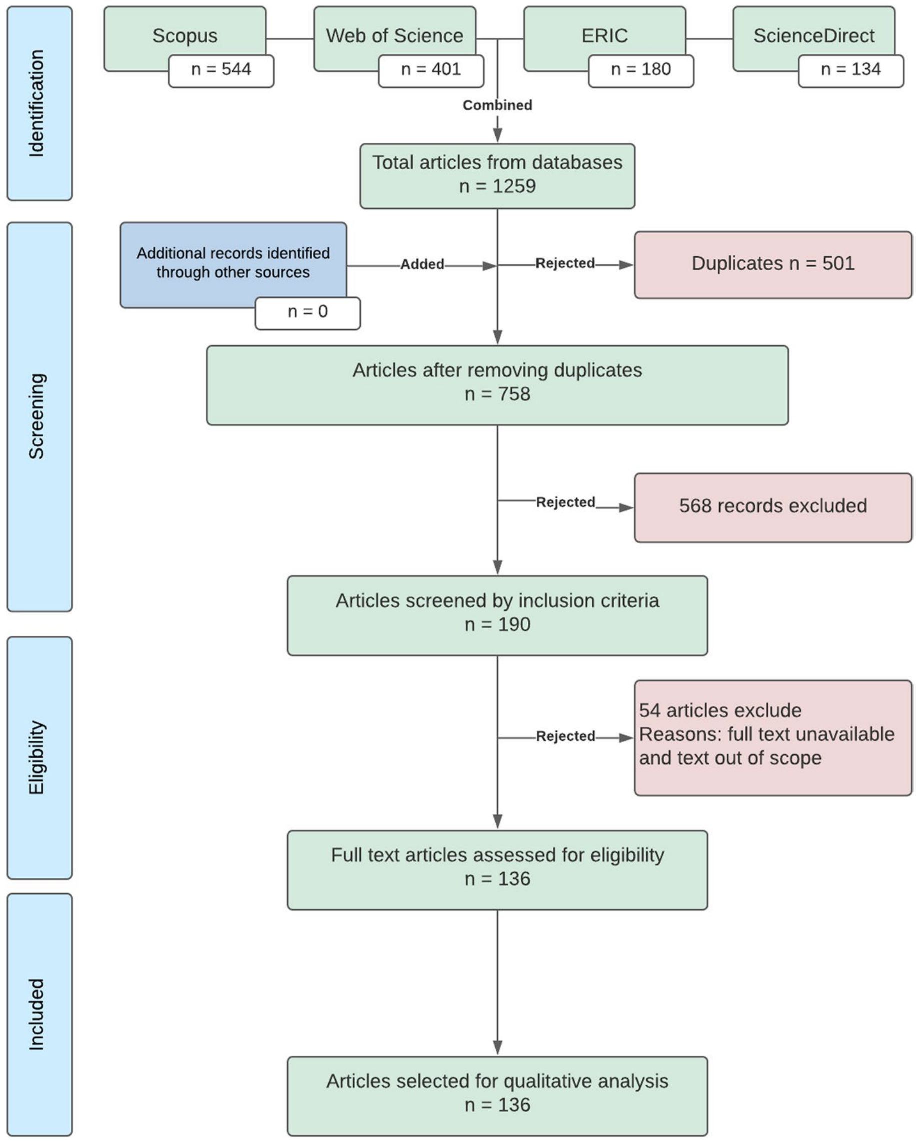


**Fig. 1** Flow diagram of the article selection process

**Table 3** Classification of education

| Category | Education program |
|---|---|
| Entry-level | Early childhood education<br>Primary education<br>Lower secondary education |
| Elementary level | Upper secondary education<br>Post-secondary non-tertiary education<br>Short-cycle tertiary education |
| Higher-level | Bachelor's or equivalent level<br>Master's or equivalent level<br>Doctoral or equivalent level |
| NA | Not elsewhere classified |

Adapted from "International standard classification of education" by UNESCO, 2011 (http://www.uis.unesco.org/Education/Documents/isced-2011-en.pdf). Copyright 2011 by UNESCO categories for coding of education programs were further generalized after the coding process to decrease the number of codes.

Concerning the methodological characteristics of each article, the classification developed by Palvia et al. (2015) was used (Table 4).

There are different categorizations for learning environments based on the used technology. For example, Mutlu-Bayraktar et al. (2019) found 14 different learning environments regarding the material type used to present content, such as computer-based learning environment, web-based learning environment, mobile learning environment, augmented reality environment, etc. Lai et al. (2019) classified technologies for educational purposes as Web 2.0 tools, mobile learning, virtual reality, augmented reality, and so on. The study aims mainly to compare AR and VR learning environments. For this reason, all other learning environments, except for AR and VR, are called traditional learning environments, including paper-based, computer-based, web-based, mobile-based learning environments. In the current study, the category of learning environment was divided into three sub-categories: virtual reality, augmented reality, and traditional learning environments. All measurements in the articles were considered, such as prior knowledge, retention, transfer, perceived difficulty, and cognitive load. Similarly, there is no pre-determined categorization for the subject matters used in the learning materials of the articles. The subject matters were further collected under fields and main fields according to ISCED Fields of Education and Training 2013 (UNESCO Institute for Statistics, 2015). After deciding the structures used in the coding, a meeting session was conducted with two senior academic staff to discuss the coding process. Considering the feedback received, the coding structure was finalized.

## Results and discussion

### RQ1: What are the general characteristics and specific design features of multimedia learning research used to investigate multimedia learning principles?

#### *Distribution by year*

When the distribution of the articles that investigated multimedia learning principles was analyzed across the years of publication, an increase, especially in recent years, was obvious, as shown in Fig. 2. The number of studies published each year was only one per year until 2004. The interest in multimedia learning principles has increased starting from 2004. This increase became drastic in 2014, but a slight decrease was observed until 2018. Compared to the previous year, the number of articles doubled in 2019, making it the highest publication per year recorded. Besides, more than half of 136 articles were published within the last six years. These findings are also

**Table 4** Research methodology

| | |
|---|---|
| 1. Speculation/commentary | 8. Field experiment |
| 2. Frameworks and conceptual model | 9. Laboratory experiment |
| 3. Literature review | 10. Design science |
| 4. Literature analysis | 11. Mathematical modeling |
| 5. Case study | 12. Qualitative research |
| 6. Survey | 13. Secondary data |
| 7. Field research | 14. Content analysis |

Reprinted from Palvia et al. (2015). Copyright 2015 by AIS Electronic Library

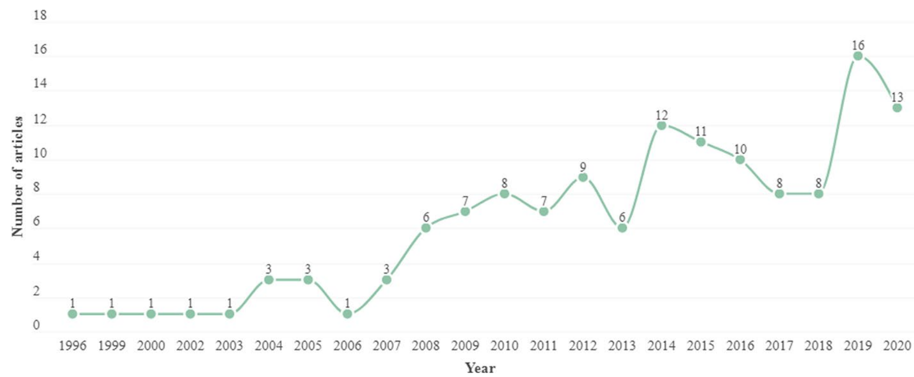


**Fig. 2** Distribution of articles by year

**Table 5** Distribution of research methodologies

| Education program | Number of studies | Percentage |
|---|---|---|
| Bachelor's or equivalent level | 98 | 72.1 |
| Not elsewhere classified | 11 | 8.1 |
| Upper secondary education | 10 | 7.4 |
| Primary education | 9 | 6.6 |
| Lower secondary education | 7 | 5.1 |
| Early childhood education | 1 | 0.7 |

consistent with Li et al. (2019), who have examined the trends and issues in multimedia learning research. For instance, the number of articles published was low (about 3–5) between 1996 and 2001. There was a steady increase in studies (from 11 to 41) after 2002, except for 2013, similar to the current review. Since multimedia learning is still emerging, the scientific contribution may increase in the coming years.

### *Education program*

Table 5 shows the educations programs of students targeted in the current study. Most research studies involved bachelor's or equivalent level students (72%), followed by upper secondary education students (7.35%), primary education students (6.62%), lower secondary education students (5.15%), and early childhood education students (0.74%). Various studies (8.09%) were not classified based on ISCED (2011). The leading target group was undergraduate level in the studies examining the principles of multimedia learning, similar to other research reviewing the cognitive load in multimedia learning (Alemdag & Cagiltay, 2018; Mutlu-Bayraktar et al., 2019). The reason why researchers prefer university students as samples is that they can be accessed more easily. In addition, few studies are focusing on younger learners. It is essential to ensure whether the multimedia learning principles are validated for various age groups, significantly the younger. Thus, more research focusing on multimedia learning principles is needed for different learner types than bachelor's or equivalent level students.

**Table 6** Distribution of research methodologies

| | Number of studies | Percentage |
|---|---|---|
| Laboratory experiment | 110 | 80.9 |
| Field experiment | 25 | 18.4 |
| Case study | 1 | 0.7 |

**Table 7** Distribution of learning environments

| | Number of studies | Percentage |
|---|---|---|
| Traditional | 131 | 96.3 |
| Virtual reality | 5 | 3.7 |
| Augmented reality | 0 | 0.0 |

## Research methodology

Research methodologies of the studies included in the research were examined based on the classification developed by Palvia et al. (2015). Most of the studies adopted the lab experiment methodology (80.9%), followed by the field experiment methodology (18.4%) (Table 6). There was only one study conducted as a case study. The result indicates that authors prefer to use quantitative methods to test the multimedia learning principles. Further studies can use qualitative and mixed methods to obtain a more robust and comprehensive understanding of the multimedia learning principles.

### RQ2: What learning environments (i.e., AR, VR, or traditional) are commonly preferred to test multimedia learning principles?

The multimedia learning principles were examined mainly in the traditional learning environments (96.3%) using paper–pencil, animations, simulations, videos, etc. Table 7 shows that only five studies tested one of the multimedia learning principles in the virtual reality environment (3.7%) (Kartiko et al., 2010; Makransky et al., 2019; Meyer et al., 2019; Parong & Mayer, 2018; Yahaya & Ahmad, 2017). However, there is no study conducted in the augmented reality learning environment. The results were aligned with the previous review by Mutlu-Bayraktar et al. (2019), investigating multimedia learning regarding cognitive load. They found that the traditional learning environment (93.62%) was preferred most often compared to AR (4.25%) and VR (2.13%) among 94 studies. Despite the limited number of studies focusing on multimedia learning principles in the AR and VR environments, there is a tendency to use AR and VR in the educational settings, as previous studies have stated (Akçayir & Akçayir, 2017; Garzón et al., 2019; Hamilton et al., 2021; Radianti et al., 2020). AR and VR positively impact learning outcomes and motivation (Akçayir & Akçayir, 2017; Selzer et al., 2019). However, there is no adequate research testing multimedia learning principles in AR and VR learning environments. More research is needed to ensure whether the multimedia learning principles are valid in AR and VR learning environments.

**RQ3: What are the measurements and subject matters commonly used in testing multimedia learning principles?**

***Measurements***

Twenty-four different measurements were detected in the reviewed studies focusing on one of the multimedia learning principles. The review revealed that the prior knowledge was measured in the majority of studies (n = 93), followed by retention (n = 64), transfer (n = 63), and perceived difficulty (n = 57). The prior knowledge of the participants was used as a control variable. However, the retention, transfer, achievement, recall, comprehension, and matching tests were intended to measure the learning outcomes, whereas measurements referred to as a cognitive load, mental effort, perceived difficulty, and the mental load was served to assess the cognitive load. Moreover, there are different variables to measure in the review articles, such as interest, anxiety, satisfaction, attitude, enjoyment, and motivation, even though their numbers are small. Figure 3 presents measurements used in the review studies.

The findings align with the previous studies (Alemdag & Cagiltay, 2018; Mutlu-Bayraktar et al., 2019). For example, Mutlu-Bayraktar et al. (2019) stated that prior knowledge was measured in nearly half of the review studies focusing on cognitive load in the multimedia learning research. After prior knowledge, the retention test, transfer test, and achievement test were the most preferred tests to measure the learning outcomes. However, the number of studies measuring motivation in multimedia learning research is less than expected. Since motivation has an essential role in the learning process (Mayer, 2014), the researchers need to examine the motivation factor in the learning process in their further research.

Assessment of the cognitive load was categorized by Brunken et al. (2003) in two dimensions: objectivity (subjective or objective) and causal relationship (direct or indirect). Objectivity refers to distinguishing between self-reporting or observing performance objectively. A causal relationship indicates whether there is a direct relationship between examined phenomena and cognitive load. For example, mental effort is

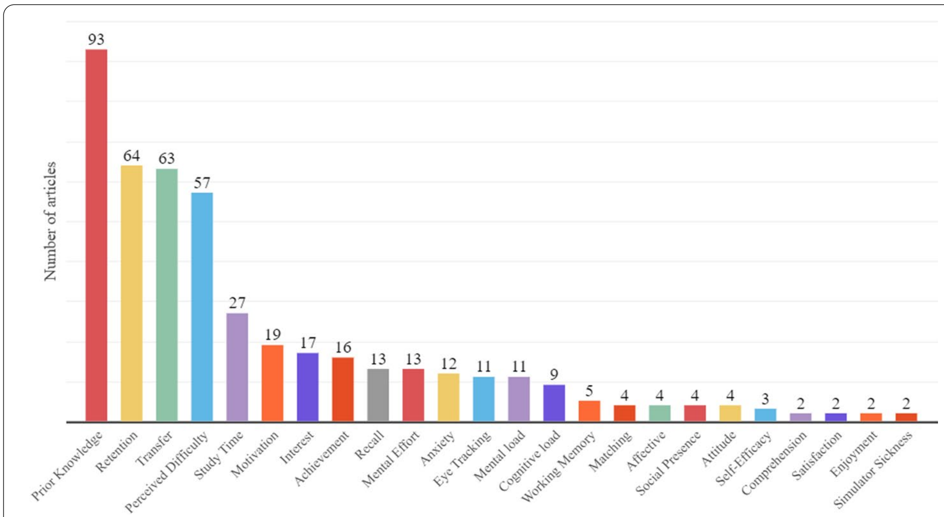


**Fig. 3** Measurements used in the review articles

considered indirect and subjective, whereas perceived difficulty is measured directly and subjectively. As shown in Fig. 3, most studies preferred subjective measurements (e.g., mental effort, difficulty) or indirect objective measurements (e.g., learning outcomes, eye-tracking, study time). However, there is a lack of research using direct and objective methods to measure the cognitive load, such as brain activity measures (e.g., fMRI) or dual-task performance. Mayer (2001) also supports that multimedia learning research is often based on a subjective and indirect assessment process, such as recall, comprehension, retention, and transfer tests. For this reason, the current research recommends that further research should use more direct and objective measurements to overcome many weaknesses of other indirect and subjective methods.

### *Subject matters*

There were eighty-six different subject matters used in the review studies, but only the first ten subject matters are displayed in Fig. 4. Review results show that researchers preferred the lightning formation topic most frequently in their studies (n = 17), followed by language learning (n = 15), authoring tool (n = 8), and braking (n = 3). The authoring tools are products used for composing, editing and managing multimedia objects such as Adobe Flash, Adobe Illustrator, Dreamweaver, and Camtasia software. In the studies choosing the authoring tools as a subject matter, instructors taught participants their properties, such as drawing with Illustrator's pen tool or adding effects and styles to the images. Some subject matters were used more frequently than others, such as lightning, brakes, and pumps, because they were used initially when the CTML was shaped (Mayer, 2017). For this reason, many researchers have adopted the same topics to test multimedia learning principles with different contexts or conditions.

Since many subjects were extracted from the reviewed studies, they were grouped based on ISCED-F (2013) to compare the previous studies more accurately. The results revealed that earth science (19.9%) was the most frequent field of education to explore multimedia learning principles, followed by history (15.0%), biology (11.8%), and engineering & technology (11.8%). Besides, almost half of the reviewed studies are from

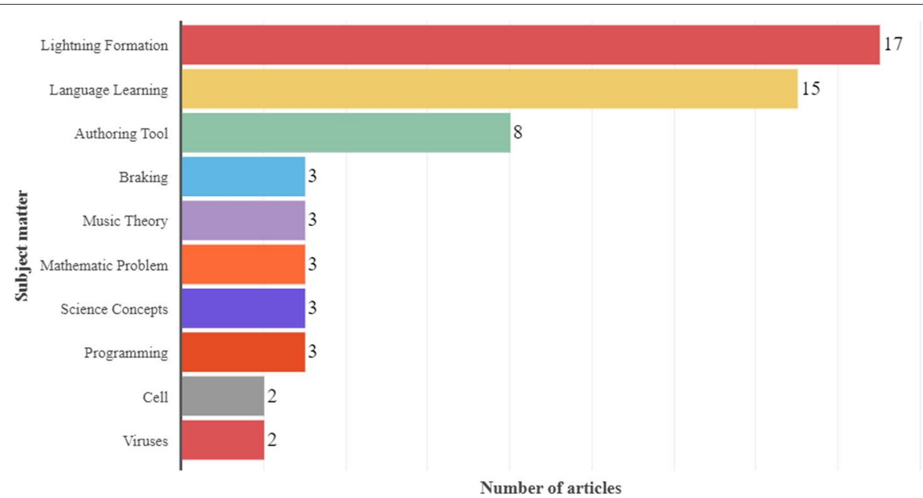


**Fig. 4** Subject matters in the review articles

natural science (48.6%), followed by humanities, and applied science. Table 8 presents the field of education of the subject matters in reviewed studies.

There are notable similarities between the current review and the prior studies investigating multimedia learning research regarding the field of education used in the reviewed studies. For example, science, technology, engineering, and mathematics (STEM) subjects (59.6%) were the most researched among the multimedia learning studies focusing on the cognitive load, followed by social science (22.3%), health (14.9), humanities (2.1%) (Mutlu-Bayraktar et al., 2019). The number for STEM fields is 62.6% for STEM fields in the current study. However, the only difference is that humanities subjects were the secondly evaluated subjects in the present review while they are the least favored. In another study by Alemdag and Cagiltay (2018), the STEM subjects (63.7%) were also taught the most frequent subjects among studies targeting eye-tracking research on multimedia learning.

As mentioned above, multimedia learning research mostly covers topics from STEM fields. Replicating existing studies using different subject matters from various fields contributes and extends the boundaries of multimedia learning research. Thus, multimedia learning principles should be validated with educational materials from non-STEM areas. Schneider et al. (2018) found that the effect of signaling varies based on instructional domains, such as geology, psychology, statistics, and so on. For this reason, different learning materials from various subject matters can be used in the same study to compare the effect of subject matters on multimedia learning principles.

### RQ4: How does using multimedia learning principles affect students' learning in different learning environments?

#### *Distribution of multimedia learning principles*

Table 9 shows the distribution of the principles of the CTML in different learning environments (AR, VR and traditional). Most studies investigated the effect of

**Table 8** Distribution of the studies based on fields of education

| Main fields | Fields of education | Frequency | Percentage |
|---|---|---|---|
| Arts | Arts | 5 | 3.70 |
| Humanities | History | 2 | 15.00 |
| | Linguistics | 15 | 11.00 |
| Social science | Education | 10 | 7.40 |
| | Law | 2 | 1.50 |
| | Statistics | 1 | 0.70 |
| | Psychology | 3 | 2.20 |
| | Sociology | 4 | 2.90 |
| Natural science | Biology | 16 | 11.80 |
| | Chemistry | 2 | 1.50 |
| | Earth Science | 27 | 19.90 |
| | Mathematics | 6 | 4.40 |
| | Physics | 15 | 11.00 |
| Applied science | Computer science | 3 | 2.20 |
| | Engineering and technology | 16 | 11.80 |
| | Medicine and health sciences | 16 | 11.80 |

**Table 9** Distribution of the multimedia learning principles based on the learning environment

| Name of principle | # of principle tested in | | | Total | Percentage |
|---|---|---|---|---|---|
| | AR | VR | Traditional | | |
| Modality principle | 0 | 0 | 43 | 43 | 21.18 |
| Redundancy principle | 0 | 1 | 40 | 41 | 20.20 |
| Multimedia principle | 0 | 0 | 27 | 27 | 13.30 |
| Signaling principle | 0 | 1 | 24 | 25 | 12.32 |
| Coherence principle | 0 | 1 | 19 | 20 | 9.85 |
| Segmenting principle | 0 | 1 | 14 | 15 | 7.39 |
| Personalization principle | 0 | 0 | 11 | 11 | 5.42 |
| Spatial contiguity principle | 0 | 0 | 9 | 9 | 4.43 |
| Temporal contiguity principle | 0 | 0 | 4 | 4 | 1.97 |
| Image principle | 0 | 0 | 4 | 4 | 1.97 |
| Pre-training principle | 0 | 1 | 2 | 3 | 1.48 |
| Voice principle | 0 | 0 | 1 | 1 | 0.49 |

multimedia learning principles in the traditional learning environment, followed by the VR environment. However, no study tested one of the multimedia learning principles in the AR learning environment. Among twelve multimedia learning principles, the modality (n = 43) was the most investigated factor, followed by redundancy (n = 41), multimedia (n = 27), signaling (n = 25), coherence (n = 20), segmenting (n = 15), personalization (n = 11), spatial contiguity (n = 9), temporal contiguity (n = 4), image (n = 4), pre-training (n = 3), and voice (n = 1).

The current results are mostly consistent with the prior studies (Alemdag & Cagiltay, 2018; Mayer, 2017; Mutlu-Bayraktar et al., 2019). For instance, the modality was the most studied principle of multimedia learning in the prior studies by Mayer (2017) and Mutlu-Bayraktar et al. (2019). However, modality was the second frequently examined principle based on Alemdag and Cagiltay's (2018) review focused on cognitive activities using eye-tracking technology. The reason may be stemmed from the focusing point of the review. In addition to the modality principle, coherence and signaling principles were the other commonly studied principles, as in the current review. Although the redundancy principle was the second most studied principle in the present review, the number was deficient in the prior studies, such as 2.38% (Alemdag & Cagiltay, 2018) and 7.8% (Mutlu-Bayraktar et al., 2019).

Some multimedia learning principles, such as multimedia, modality, coherence, and redundancy, were examined earlier than other multimedia learning principles, including image, voice, or pre-training principles. That may be why some multimedia learning principles are over-studied than others. The researchers should focus more on voice, pre-training, image, spatial contiguity, and temporal contiguity for further research. There is also a massive gap for all multimedia learning principles in the VR and AR learning environments. Thus, the multimedia learning principles should be tested in the VR and AR learning environments to ensure validity. Educational technologists can consider the results when applying multimedia learning principles to their learning materials in VR and AR environments.

#### *Multimedia learning principles and learning outcomes*

Learning outcomes in the reviewed studies were assessed by different measurements, such as retention, transfer, recall, and achievement. It was aimed to present the distribution and effects of measurements based on multimedia learning principles for each learning environment. However, there was no study in the AR learning environment and only five studies in the VR learning environment. For this reason, Table 10 shows only how each multimedia learning principle affects the learning outcomes in traditional learning environments.

The "Affected Positively" column shows how many studies have found the effect of each multimedia learning principle on learning outcomes positively. The percent column represents the ratio of the number in the "Affected Positively" column to the number of studies examining each multimedia learning principle. As seen from Table 10, learning was not positively affected in all studies for each principle, except for temporal contiguity and pre-training principles (because of the limited number of studies). Even though the number of studies (n = 17) investigating the modality effect was the highest, it made a minor contribution to learning outcomes among the reviewed studies based on retention scores. The percentages are higher for transfer (47.1%), recall (42.9%), and achievement (62.5%). However, based on a review by Mayer (2017), 42 out of 51 (82.3%) studies confirmed the positive effect of the modality principle on learning outcomes, including transfer, retention, and comprehension tests. The conflicting results between the current and previous studies can be explored in future research.

The second most frequently examined principle was the signaling principle. It also improved learning by guiding learners' attention in almost two-thirds of the reviewed studies. The meta-analysis by Richter et al. (2016) and Schneider et al. (2018) also found similar findings. For instance, Schneider et al. (2018) found that retention scores (84.2%) and transfer scores (78.2%) of studies were increased when essential parts of text or graphics were highlighted. The reason may be caused by the reducing effect of signaling on the complexity and difficulty of learning materials. However, the signaling effect may not be the same for all learners. It may even hinder learning for learners with high prior knowledge (Kalyuga, 2014; Richter et al., 2016). The signaling effect should be investigated with novice and knowledgeable learners to compare them. Besides, the results can be validated by using eye-tracking methods used for tracing learners' attention. Further research can compare findings from tests and eye-tracking whether they are compatible.

Similar to the signaling principle, many studies have shown that segmenting principle positively impacted the learning process. For example, the retention test (71.4%) and transfer test (83.3%) results of the reviewed studies showed that the application of the segmenting principle caused better learning when the multimedia representations were broken into self-paced segments. The results aligned with the prior meta-analysis (Rey et al., 2019), revealing that most studies focusing on the segmenting principle found a positive effect on retention (67.2%) and transfer scores (60.7%). The educational technologists can apply the segmenting principle in their learning materials to enhance the learning process by considering the results. Since the segmenting effect has two different key features, it can be caused by breaking multimedia tutoring into sequential parts or permitting learners to control the multimedia instruction's pace. The current review did not examine the effects of both features on the learning

**Table 10** Distribution and effects of measurements based on multimedia learning principles

| Name of principle | Retention | | | Transfer | | | Recall | | | Achievement | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | f | Affected positively | % | f | Affected positively | % | f | Affected positively | % | f | Affected positively | % |
| Modality | 17 | 3 | 17.6 | 17 | 8 | 47.1 | 7 | 3 | 42.9 | 16 | 10 | 62.5 |
| Redundancy | 13 | 4 | 30.8 | 14 | 7 | 50.0 | 4 | 2 | 50.0 | 21 | 7 | 33.3 |
| Multimedia | 10 | 6 | 60.0 | 9 | 6 | 66.7 | 7 | 4 | 57.1 | 13 | 9 | 69.2 |
| Signaling | 14 | 8 | 57.1 | 14 | 10 | 71.4 | 4 | 3 | 75.0 | 9 | 7 | 77.8 |
| Coherence | 9 | 4 | 44.4 | 11 | 7 | 63.6 | 1 | 1 | 100.0 | 1 | 0 | 0.0 |
| Segmenting | 7 | 5 | 71.4 | 12 | 10 | 83.3 | 2 | 2 | 100.0 | 5 | 4 | 80.0 |
| Personalization | 8 | 3 | 37.5 | 7 | 3 | 42.9 | 0 | – | – | 4 | 3 | 75.0 |
| Spatial cont | 5 | 2 | 40.0 | 6 | 4 | 66.7 | 1 | 0 | 0.0 | 3 | 2 | 66.7 |
| Temporal cont | 1 | 1 | 100.0 | 2 | 2 | 100.0 | 2 | 0 | 0.0 | 1 | 0 | 0.0 |
| Image | 0 | – | – | 0 | – | – | 0 | – | – | 0 | – | – |
| Pre-training | 1 | 1 | 100.0 | 1 | 1 | 100.0 | 0 | – | – | 1 | 1 | 100.0 |
| Voice | 1 | 0 | 0.0 | 1 | 1 | 100.0 | 0 | – | – | 0 | – | – |

outcomes. Further meta-analysis may compare their effect sizes to distinguish their effects on learning outcomes and cognitive load.

Application of the redundancy principle did not enhance learning in more than half of the reviewed studies (n = 41). The number of studies finding a positive effect of the redundancy principle is deficient, especially regarding retention scores (30.8%) and achievement scores (33.3%). On the contrary, Mayer (2017) found that 13 out of 13 studies validated the positive effect of the redundancy principle on learning outcomes. Adesope and Nesbit (2012) also found a similar result with Mayer (2017) on retention performance, but not the same for transfer performance. More studies are needed as there are conflicting results about the redundancy principle positively contributing to learning. The number of the study is very low for voice, pre-training, image, and temporal contiguity principles to compare the results with the previous reviews. Thus, the researchers should also examine them more in their further research.

## Implications and future research

This systematic review identified the following existing gaps and needs in the research. This systematic review shows that the majority were conducted with undergraduate students. It is crucial to validate multimedia learning principles for various age groups, significantly the younger. In addition, multimedia learning principles were mainly tested with subjects from STEM fields. Replicating existing studies using different subject matters from non-STEM fields with different types of learners contributes and extends the boundaries of multimedia learning principles. Thus, more research focusing on multimedia learning principles is needed for different learner types and subjects from non-STEM fields.

The use of objective methods in cognitive load measurements helps explain multimedia principles' effects. The current review study indicated a lack of research using objective measures for the cognitive load, such as brain activity measures (e.g., fMRI) or dual-task performance. It is recommended that future studies should use objective measurements in future studies to overcome many weaknesses of other indirect and subjective measurements and compare the results with prior studies using subjective measures.

AR and VR positively impact learning outcomes and motivation (Akçayir & Akçayir, 2017). However, as our findings reveal, there is a massive gap for all multimedia learning principles in the VR and AR learning environments. Thus, more research is needed to ensure whether the multimedia learning principles are valid in AR and VR learning environments. Further studies may directly affect the investment in VR and AR technologies and the integration of these technologies into the learning process by the teachers.

In the traditional learning environment, the number of the study is very low for voice, pre-training, image, and temporal contiguity principles. In addition, there are conflicting results about the positive effect of multimedia learning principles on learning. Thus, the researchers should also examine them more in their further research. Educational technologists can benefit from this study as it can guide them when designing educational materials for each learning environment based on the results.

## Conclusion

Several reviews and meta-analyses have investigated multimedia learning principles. For instance, Rey et al. (2019) examined the segmenting principle in a current meta-analysis. In addition, the signaling principle has been reviewed by Schneider et al. (2018) in another meta-analysis. They have mainly focused on one of multimedia learning principles. This study provides results from a systematic review of all multimedia learning principles regarding learning environments, outcomes, methodologies, measurements, subject matters, publication years, the field of education, and education levels, based on 136 journal articles. When looking at the published years, there was an increasing trend in research focusing on multimedia learning principles. Most reviewed studies (72%) used bachelor's or equivalent level students as participants. Except for one case study, all studies adopted laboratory experiments (80.9%) and field experiments (18.4%).

The modality and redundancy were commonly investigated multimedia learning principles. However, the spatial contiguity, temporal contiguity, image pre-training, and voice principles were underresearched. The review also showed that commonly measured factors were learning outcomes (i.e., retention, transfer, and achievement performance) and cognitive load, such as perceived difficulty, mental effort, etc. Besides, most studies have been conducted in the traditional learning environments (96.3%), followed by virtual reality learning environments (3.7%). However, augmented reality was not preferred as a learning environment among the reviewed studies.

This review is valuable for researchers to understand multimedia learning principles in different learning environments. The study has also identified the gaps remaining in the literature. Researchers can use this paper's highlighted gaps and future directions for future empirical studies.

There are a few limitations in the review. Only specific databases were used to gather the articles (i.e., Scopus, Web of Science, ERIC, ScienceDirect). It is possible to find papers focusing on multimedia learning principles in other databases. The research is also limited by using only journal articles in the review. The current study can be expanded and validated for further investigation by including other databases (i.e., Springer, IEEE, and Google Scholar) and article types, such as conference proceedings, thesis/dissertations, and book chapters. Lastly, all other learning environments, including paper-based, computer-based, web-based, mobile-based learning environments and except for AR and VR, are called traditional learning environments, as they do not fit the scope of the study. Further research can explore other learning environments and compare them with AR and VR environments.

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### Competing interests
The authors declare that they have no competing interests.

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