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Cognitive load in multimedia learning environments: A systematic review

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A B S T R A C T

The purpose of this study was to review articles involving cognitive load and multimedia learning between 2015 and 2019 in a systematic way. 94 articles were reviewed in terms of the types of cognitive load, multimedia learning principles, cognitive load measurements, the investigated dependent and independent variables, cognitive processes, the types of multimedia learning environments and the demographic characteristics of the studies. The results revealed that reviewed studies indicated the type of cognitive load seem to have investigated the extraneous cognitive load more frequently. The most studied multimedia learning principles in reviewed articles were modality principle, seductive details effect and signaling/cueing principle respectively. Most reviewed cognitive load studies on multimedia learning were conducted by researchers in Europe, especially in Germany, followed by Asia, America, Australia, and Africa. Research results showed that most cognitive load studies in multimedia learning environments conducted thus far have utilized STEM subjects. Higher education students were the primary participant group in the cognitive load in multimedia learning research as well. There was a tendency to use subjective methods more often than objective methods to measure cognitive load in investigations. In addition to cognitive load, learning, prior knowledge, and motivation were measured most frequently in these studies. In the reviewed studies, multimedia design, material type, presentation format, and individual differences were the most selected focus of research. Research results were interpreted and a number of gaps in cognitive load research relating to multimedia learning were identified.

1. Introduction

An increase in digital and online resources has been accompanied by a rapid increase in stimulant information, prompting a tendency to design additional multimedia learning environments (Clark & Mayer, 2016; Mayer, 2017). Multimedia learning is one of the rapidly developing theories that has grown in tandem with the spread of technology usage in education, and an increase in opportunities to design learning environments that stimulate more than one channel (Liu, Jang, & Roy-Campbell, 2018). Changes in technology and information types have necessitated the design of multiple channel learning environments. Multimedia designs which appeal to different sensing and processing channels are defined as those that present words (narration or text) and pictures (illustration, photography, animation, video, etc.) together (Mayer, 2014a; Schnotz, 2005). Developments in educational technology have made it possible for instructional designers to provide increasingly images, diagrams, and screen displays in the learning environment. Hence, instructional designers should account for the way novel information is processed by learners when designing visual displays, and the ways specific design techniques can facilitate learning (Renkl & Scheiter, 2017; Schroeder & Cenkci, 2018).

The working structure of human cognition must be taken into consideration when designing multimedia messages to allow the learning to progress according to each learner's own cognitive process. Learning is accomplished by establishing connections between compatible verbal and pictorial representations (Mayer, 2005). Its focal point is the construction of information obtained from verbal

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and pictorial elements (Butcher, 2014; Mayer, 2014a). Learners handle new information during knowledge construction through two processors, depending on representation form: verbal or pictorial. New schema involves a process of selecting and organizing relevant information and integrating it with prior knowledge; it can only be produced through cognitive engagement (Mayer, 2014a). Researchers have begun to conduct studies within the scope of this theory, searching for methods that would enhance the process of constructing information from stimuli presented through different channels (Mayer, 2005; Schnotz, 2005). These studies reveal that intensive and complicated information coming from verbal and pictorial channels can present a mental challenge (Sweller, 1994). Starting with this understanding, the concept of cognitive load has gained importance.

Mental activity realized simultaneously with working memory is called "cognitive load" (Paas, Renkl, & Sweller, 2004). Cognitive load management is embodied within the framework of the Cognitive Load Theory (Sweller, 2005). Cognitive load theorists contend that the design and presentation of instructional material should reflect the significant limitations of the human information processing system (Paas, van Gog, & Sweller, 2010; Sepp, Howard, Tindall-Ford, Agostinho, & Paas, 2019). A number of design principles have been recommended for managing the amount of cognitive load and enhancement of learning, acknowledging the limited capacity of working memory in the multimedia learning environment design process (Mayer, 2005; Paas, Tuovinen, Tabbers, & Van Gerven, 2003). A substantial amount of educational research has investigated the effects of design principles on cognitive load (Andrade, Huang, & Bohn, 2015; Castro-Alonso, Wong, Adesope, Ayres, & Paas, 2019; Craig & Schroeder, 2017; Leahy & Sweller, 2016; Park, 2015; Rey et al., 2019; Schroeder & Cenkci, 2018; Song & Bruning, 2016; Yang, 2016), Various cognitive load measurements have been necessary to reveal the effects of these studies. Therefore, research about learning and instruction requires reliable and valid methods of cognitive load measurement (Cheng, Lu, & Yang, 2015; Korbach, Brünken, & Park, 2017; Paas, Tuovinen, et al., 2003).

Review studies also made a contribution to cognitive load and multimedia learning literature. Recent reviews focused on hypertext reading, neuroimaging, multimedia learning principles such as worked examples, and pedagogical agent, cognitive load measurement, cognitive load type, designing message with spoken words, split-attention, modality and redundancy effects, simulation-based training, and working memory in a historical sequence (Anmarkrud, Andresen, & Bråten, 2019; DeStefano & LeFevre, 2007; Kalyuga, 2011; Kalyuga, 2012; Naismith & Cavalcanti, 2015; Schroeder & Adesope, 2014; Taylor, 2013; van Gog, Paas, & Sweller, 2010; Whelan, 2007; Wouters, Paas, & van Merriënboer, 2008). Review results reported implications to design multimedia learning environments based on cognitive load (e.g., DeStefano & LeFevre, 2007; Kalyuga, 2012; Naismith & Cavalcanti, 2015; Schroeder & Adesope, 2014; Taylor, 2013; van Gog et al., 2010; Wouters et al., 2008), refining cognitive load theory (e.g., Kalyuga, 2011), to measure cognitive load in the studies (e.g., Anmarkrud et al., 2019; Whelan, 2007). For example, Wouters et al. (2008) suggested guidelines to deal with intrinsic and extraneous loads, and improving germane load to design animated models. Kalyuga (2011) suggested using intrinsic and extraneous load types and excluding germane load in Cognitive Load Theory in a theoretical perspective in his review study. Recent reviews examined different aspects of cognitive load research separately in each study. Their results are important to lead researchers for future studies however there is also a need for systematic reviews related to cognitive load and multimedia learning which examines different aspects of cognitive load in multimedia learning such as multimedia learning principles, cognitive load type, cognitive load measures, etc. at once in the literature.

In this study the current researchers systematically reviewed up-to-date literature on cognitive load in multimedia learning in diverse databases, understanding that cognitive load is vital in multimedia learning, and familiarity with relevant research is important. Of particular interest were cognitive load studies that investigated various kinds of cognitive load, the measurement tools employed, the cognitive processes involved, and other variables that were assessed with cognitive load. The following research questions were formed accordingly, and the results were discussed as they relate to the articles reviewed.

RQ1. What are the characteristics of multimedia learning research used to investigate cognitive load?
RQ2. What are the investigated principles of multimedia learning on cognitive load in multimedia learning research?
RQ3. What are the types of cognitive load associated with multimedia learning research?
RQ4. What are the cognitive load measurements used in multimedia learning research?
RQ4.1. What are the measurements used in the reviewed studies beyond cognitive load measures?
RQ5. What are the investigated dependent variables on cognitive load in multimedia learning research?
RQ6. What are the investigated independent variables on cognitive load in multimedia learning research?
RQ7. What are the cognitive processes associated with cognitive load measurements in multimedia learning research?
RQ8. What are the types of multimedia learning environments?
RQ9. What is the focus of research on cognitive load in multimedia learning research?

2. Background

2.1. Cognitive load

The Cognitive Load Theory attempts associations with instructional design principles on the basis of human cognitive architecture theories. The instructional principles of the theory are based on long-term memory and working memory assumptions about human cognitive architecture (Paas & Sweller, 2014, p. 37). The Cognitive Load Theory emphasizes that all novel information is initially processed by working memory which has capacity and duration limitations; the information is then stored in long-term memory which is unlimited (Anmarkrud et al., 2019; Sweller, van Merriënboer, & Paas, 2019). The aim of instructional design should be to reduce unnecessary working memory loads, and free the capacity for learning-related processing to accommodate the limited capacity of working memory (Sweller, 2010; Sweller, Ayres, & Kalyuga, 2011).

The Cognitive Load Theory claims there are three categories of cognitive load on working memory in any learning task. These include intrinsic cognitive load, extraneous cognitive load, and germane cognitive load (Paas & Sweller, 2014, s. 39; Sweller et al., 2019). The intrinsic cognitive load is determined by the complexity of a learning task and the results from element interactivity. The number of interacting information elements belonging to a learning task is defined as “element interactivity.” The learning task becomes more complex as the intrinsic cognitive load becomes higher. However, as a learner's prior knowledge also plays a role in determining the intrinsic cognitive load, it is not merely a feature of instructional content (Canham & Hegarty, 2010; Park, Korbach, & Brünken, 2015).

Extraneous cognitive load is a cognitive load that causes an unnecessary increase in interactional elements to be processed by the learner, and it is a result of inappropriate instructional design (Paas & Sweller, 2014, p. 38). Therefore, the instructional approach (for example, explanation adequacy or instructional material integration) critically affects the extraneous cognitive load. Germane cognitive load is a load that emerges during the formation and regulation of mental structures. The capacity that remains from extraneous and intrinsic loads on working memory capacity is used for the germane cognitive load (Paas & Sweller, 2014, p. 38). The capacity left for the germane cognitive load is effective in realizing learning. In conclusion, according to the Cognitive Learning Theory, the total cognitive loads counted in the learning process should not exceed the learning capacity of the learner. Therefore, designers should analyze content to be taught, and consider the load processed in working memory while using texts, pictures, and graphs.

2.2. Cognitive load and multimedia learning

Empirical research on learning and instruction commonly utilizes the Cognitive Load Theory as a theoretical framework (Korbach et al., 2017). The focus of these studies is to identify methods and techniques that might reduce the working memory load of cognitive load types in instructional design. Similarly, this topic is important in multimedia learning studies. Multimedia Learning is defined as the learning realized when constructing mental representations through pictures and words (Mayer, 2014b, p. 3). The Cognitive Theory of Multimedia Learning, which is based on the Cognitive Load Theory, was developed in light of the studies conducted. The theory addresses how individuals process information, and how they learn through multimedia approaches (Mayer, 2014a, p. 44). The theory encompasses three fundamental assumptions: (1) people have separate channels for processing visual and audio information, (2) each channel has a limited amount of information per unit of time, and (3) people experience active learning by accessing related information, organizing the selected information through mental structures, and integrating them with previous mental structures. According to the theory, multimedia learning is realized (Mayer, 2014a, p. 52) as follows: Initially, words and pictures are selected by sensory memory which has an unlimited capacity, and it is subsequently transferred to working memory. Knowledge is organized in working memory, which has a limited capacity, and integrated with knowledge in long-term memory.

The instructional design should be appropriate for a given individual's cognitive processing, and avoid overloading the memory demand present during learning. Three types of learner processing are realized in information processing according to the Cognitive Theory of Multimedia Learning: extraneous processing, essential processing, and generative processing (Mayer, 2014a, p. 59). Essential processing is what is realized in the process of selecting and organizing the realized ones from those presented via multimedia. Words and pictorial representations related to the material presented as a result of this processing are constructed in working memory. It resembles the intrinsic cognitive load associated with Cognitive Load Theory (Mayer, 2014a, p. 60). Extraneous processing refers to processing that results from the instructional design and does not serve instructional goals. It resembles the extraneous cognitive load in Cognitive Load Theory (Mayer, 2014a, p. 60). Generative processing encompasses received information organization and its integration with previously related knowledge. It resembles the germane load in Cognitive Load Theory.

Multimedia learning studies suggest that various instructional principles contribute to the learning process for every type of cognitive load (Mayer, 2014a) The principles suggested for minimizing extraneous processing are as follows (Mayer & Fiorella, 2014): coherence principle, signaling principle, redundancy principle, spatial contiguity principle, and temporal contiguity principle. The principles suggested for managing essential processing are (Mayer & Pilegard, 2014): segmenting principle, pre-training principle, and modality principle. The principles suggested for fostering generative processing are: multimedia principle (Butcher, 2014), personalization principle, voice principle, embodiment principle (Mayer, 2014a,b,c), guided discovery principle (de Jong & Lazonder, 2014), self-explanation principle Wylie & Chi, 2014), and drawing principle (Leutner & Schmeck, 2014). The three-partite nature of cognitive load-intrinsic cognitive load, extraneous cognitive load, and germane cognitive load are of importance for the generation and design of multimedia learning materials and, therefore, should be seriously considered.

2.3. Measurement of cognitive load in multimedia learning

There are various methods used to measure cognitive load which cannot be observed directly; thus, it is a challenge to assess cognitive load (Brunken, Plass, & Leutner, 2003; DeLeeuw & Mayer, 2008). Brunken et al. (2003) classify cognitive load measurement methods into two dimensions: objectivity and casual relationship. Objectivity refers to using the reader's own, self-reported tools or objective observations, physiological conditions, and performance. Causal relationship is related to whether there is a direct or indirect link between cognitive load and observed phenomenon (see Brunken et al., 2003).

Subjective measures are the most common methods used to assess cognitive load in the literature. The development of these measures was based on the assumption that individuals can “evaluate their own cognitive processes” and rate the cognitive load they experience during completion of a task (Anmarkrud et al., 2019, p. 5). There are both “indirect” types such as self-reported mental effort (Paas, van Merriënboer, & Adam, 1994), and “direct” types such as material difficulty ratings (Kalyuga, Chandler, & Sweller,

1999) of subjective measures (Brunken et al., 2003). Although subjective measures are commonly employed methods to assess cognitive load in the literature, there are methodological limitations: reliability and validity, single item cognitive load measurement, inadequate clarification of the difference between cognitive load constructs, various and inconsistent constructs to operationalize cognitive loads in subjective measures, and the time of cognitive load assessment (Anmarkrud et al., 2019; Brunken et al., 2003). There are also attempts to measure different types of cognitive load with varying assessment tools discussed in the literature (Cierniak, Scheiter, & Gerjets, 2009; DeLeeuw & Mayer, 2008; Leppink, Paas, Van der Vleuten, Van Gog, & Van Merriënboer, 2013). However, subjective measures create concerns in multimedia learning due to “the lack of data and the psychometric properties of subjective measures” (Anmarkrud et al., 2019, p. 16).

Objective measures of cognitive load consist of various methods such as dual-task methodology and physiological measures (Anmarkrud et al., 2019). Indirect objective measures include analysis of performance outcome, analysis of behavioral patterns or physiological conditions and functions that correlate with the learning process (e.g. time-on-task, lost-in-hyperspace, eye-tracking), and physiological measures such as heart rate and pupil dilation (Brunken et al., 2003). Eye-tracking helps record eye-movement data while an individual is looking at a screen or another medium such as a book, etc. Various measures from eye-tracking data such as cognitive pupillary responses, fixation duration, fixation count, blink rate, blink duration, and blink latency can be acquired (Kruger & Doherty, 2016). Direct objective measures include functional magnetic resonance imaging (fMRI), positron-emission tomography (PET), functional near-infrared spectroscopy (fNIRS), electroencephalography (EEG), and dual-task-paradigm (Anmarkrud et al., 2019; Antonenko, Paas, Grabner, & van Gog, 2010; Brunken et al., 2003). The use of fMRI and PET as neuroimaging techniques help collect data related to blood flow during neural activity (Antonenko et al., 2010). fNIRS is a compact device compared to fMRI and is used alternatively to measure neural activity for this reason. It helps collect cortical blood flow data (Antonenko et al., 2010). EEG is another neuroimaging technique: it provides data from the brain's electrical activity (Kruger & Doherty, 2016). A secondary task presented in a dual-task paradigm is expected to cause memory load and is added to a primary task. This allows for an assessment of cognitive load in two ways: the performance in the primary task is assessed, and the performance in the secondary task is assessed (Brunken et al., 2003).

3. Method

The present study is a literature review of cognitive load in multimedia learning research. A literature review identifies, selects, and synthesizes research studies in order to provide a summary of the topic under investigation (Oakley, 2012).

Planning:

- Selection of indexes
- Definition of inclusion and exclusion criteria
- Definition categories for the analysis

Conduct the review:

- Study selection
- Data extraction
- Data synthesis
- Data coding

Reporting the review:

- Analysis of results
- Discussion of findings
- Trends and conclusions of the review

3.1. Search strategy

Web of Science, Education Resources Information Center (ERIC), Scopus, and EBSCO databases were utilized in this study. “Cognitive load” and “multimedia” keywords were used to search for relevant publications. Articles published as full texts in peer-reviewed journals were indexed using these databases. The time period selected for the review extended from January 2015 to March 2019. Studies focused on cognitive load measurements in multimedia learning environment. Only English studies were included. Conference papers, theses and book chapters were not selected for the review. Inclusion and exclusion criteria were presented in Table 1.

3.2. Study selection process

The initial literature search returned 511 articles from all indexes. The articles were screened and selected using associated keywords.

First, search data was downloaded as Microsoft Excel document files from web pages of indexes. Eighty-three articles duplicated

Table 1
Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Articles should have been published in journals which were indexed by Web of Science, Education Resources Information Center, Scopus, EBSCO databases	Conference papers, thesis, and book chapters were not selected.
Article was peer-reviewed.	Studies must not be exclusively about only cognitive load.
Article was full-text.	Non-English.
Article must be published between January 2015 and March 2019.	Article must not be review, meta-analysis, or commentary article.
Article was original and empirical research article.	
Article must involve cognitive load measurements in multimedia learning environment	

in various indexes were selected and removed from other lists.

Second, each researched keyword and abstract was reviewed for scope and suitability for inclusion in the study, based on predetermined inclusion criteria: cognitive load measurements and multimedia learning. Only original investigations measuring cognitive load in multimedia learning were selected for this review. Also, unclear investigative reports were saved for a detailed review to fully assess whether they met inclusion criteria. In the end, seventy-five articles were excluded.

Third, full texts of the remaining 351 articles were critically evaluated based on the criteria set in terms of the research questions. During the evaluation process, 257 articles were excluded in terms of inclusion and exclusion criteria. Finally, 94 articles were selected for systematic review.

3.3. Categories for analysis and data coding

A group of categories were defined according to each research question. The categories helped in coding the data. The following features that fell within the scope of the research questions were investigated and coded as appropriate:

RQ1. What are the characteristics of multimedia learning research used to investigate cognitive load?

RQ2. What are the investigated principles of multimedia learning on cognitive load in multimedia learning research?

- Coherence Principle
- Signaling Principle
- Redundancy Principle
- Spatial Contiguity Principle
- Temporal Contiguity Principle
- Segmenting Principle
- Pre-training Principle
- Modality Principle
- Multimedia Principle
- Personalization Principle
- Voice Principle
- Image Principle

RQ3. What are the types of cognitive load associated with multimedia learning research?

- Extraneous load
- Intrinsic load
- Germane load

RQ4. What are the cognitive load measurements used in multimedia learning research?

RQ4.1. What are the measurements used in reviewed studies beyond cognitive load measures?

RQ5. What are the investigated dependent variables for cognitive load in multimedia learning research?

RQ6. What are the investigated independent variables for cognitive load in multimedia learning research?

RQ7. What are the cognitive processes associated with load measurements in multimedia learning research?

RQ8. What are the types of multimedia learning environments?

- Computer based multimedia learning environments
- Web based multimedia learning environments
- Mobile multimedia learning environments
- e-book multimedia learning environments
- VR multimedia learning environments

Table 2
Cognitive load types in reviewed articles.

Cognitive Load Type	f	%	Sample Research
Extraneous	14	14.9	Örün & Akbulut, (2019)
Germane	1	1.1	Costley & Lange; (2017)
Extraneous-Intrinsic	14	14.9	Brom, Dechterenko, Frollova, Starkova, Bromova, & D'Mello, 2017
Extraneous-Germane	2	2.1	Johnson, Ozogul, & Reisslein, 2015a,b
Overall	19	20.2	Chang, Warden, Liang, & Chou, 2018a,b
Not mentioned	44	46.8	Feldon, Franco, Chao, Peugh, & Maahs-Fladung, (2018)
Total	94	100	

RQ9. What is the focus of research on cognitive load in multimedia learning research?

4. Results

4.1. Research question one (types of cognitive load)

RQ1: What are the types of cognitive load associated with multimedia learning research?

The study analyzed cognitive load types investigated in earlier studies that fell within the scope of the present study. This analysis utilized extraneous, intrinsic, and germane cognitive load classifications investigated within the scope of Cognitive Load Theory. Table 2 presents the frequency values in relation to each cognitive load. Hence, of the 94 studies, extraneous cognitive load was performed in 14; germane cognitive load was performed in one; both extraneous and intrinsic cognitive loads were performed in 14; and both extraneous and germane loads were performed in two. An extraneous cognitive load is a load generated in working memory due to cognitive processing arising from the instructional design (Mayer, 2014a, p. 60). The total number of studies that measured extraneous cognitive load caused by the design of instructional material in multimedia learning studies was 30 (31%), and followed by 14 studies with intrinsic cognitive load. Intrinsic cognitive load is defined as the complexity of a learning task due to element interactivity of the learned topic. This was the type of cognitive load investigated in 15% of the studies. Germane cognitive load measurement was used in only one study. In this regard, studies that indicated the type of cognitive load seem to have investigated the extraneous cognitive load more frequently. On the other hand, 19 other studies performed overall cognitive load measurement. Additionally, 44 analyzed studies did not indicate the type of cognitive load. This seems to indicate that the connection established with the theoretical base was insufficient in the analyzed studies.

4.2. Research question two (principles of multimedia learning)

RQ2. What are the investigated principles of multimedia learning on cognitive load in multimedia learning research?

Of the 94 studies reviewed, 51 were conducted with multimedia principles and effects: they examined the effects of different multimedia principles on cognitive load. The most studied multimedia learning principles in reviewed articles were modality principles (17.6%), seductive details effect (17.6%), and signaling/cueing principles (15.7%, Table 3). Almost all of the proposed multimedia learning principles for minimizing extraneous processing (Richter, Scheiter, & Eitel, 2018), managing essential processing (Chen & Yen, 2019), and fostering generative processing (Zander, Wetzel, Kühl, & Bertel, 2017) were studied in the reviewed investigations.

4.2.1. Modality principle

People learn better in environments where graphics (pictorial, visual) and audio narration are presented together, rather than in environments with graphics and written words (Mayer, 2014a). However, the fact that information is presented to both visual and

Table 3
Multimedia Learning Principles and Effects used in the cognitive load studies on multimedia learning.

Principles/Effect	f	%	Sample Research
Modality Principle	9	17.6	Chen and Yen (2019)
Seductive Details Effect	9	17.6	Eitel et al. (2019)
Signaling/Cueing Principles	8	15.7	Richter et al. (2018)
Personalization Principle	5	9.8	Zander et al. (2017)
Spatial/Contiguity Principle	5	9.8	Makransky, Terkildsen, and Mayer (2019)
Redundancy Principle	4	7.8	Rop, Schüler, Verkoeijen, Scheiter, and Gog (2018)
Multimedia Principle	3	5.9	Park (2015)
Coherence Principle	3	5.9	Beege, Schneider, Nebel, & Mittangk, Rey (2017)
Voice Principle	2	3.9	Craig and Schroeder (2017)
Segmenting Effect	2	3.9	Andrade et al. (2015)
Learner Control Effect	1	1.9	Chen and Yen (2019)

auditory channels at the same time reduces cognitive load (Hughes, Costley, & Lange, 2019; Oberfoell & Correia, 2016). In modality principle it is better to use narration rather than texts because individuals can pay attention to visuals while listening to audio. Hence, representation holding does not happen during the simultaneous presentation of the picture and words through narration. In comparison to on-screen text and picture representations, there is a decrease in cognitive load and an increase in learning, which has been revealed in the literature (Alvarez, Alnizami, Dunbar, Jackson, & Gilbert, 2015a; Inan et al., 2015; Scheiter, Schüler, Gerjets, Huk, & Hesse, 2014).

4.2.2. Seductive details effect

The seductive details effect has been reported in the literature with results indicating that the inclusion of irrelevant information in a text decreases the comprehension of the text as a whole (Garner, Brown, Sanders, & Menke, 1992; Harp & Mayer, 1998). Multimedia studies on seductive details concluded that due to limited working memory capacity, irrelevant information causes more cognitive load (Abercrombie, 2013; Park, Moreno, Seufert, & Brünken, 2011; Sanchez & Wiley, 2006). This effect, whose effect on cognitive load could be decreased with proper arrangements made in the design process, has been investigated more in recent studies (Eitel, Bender, & Renkl, 2019; Korbach, Brünken, & Park, 2016; Scheiter et al., 2014; Schneider, Wirzberger, & Rey, 2019; Z.; Wang & Adesope, 2016; Z.; Wang, Sundararajan, Adesope, & Ardasheva, 2017).

4.2.3. Signaling/cueing principles

Multimedia learning environments have rich learning content and learners have limited capacity. When learners are supported with signaling or cueing to focus correct resources, they demonstrate better learning performance (Kalyuga et al., 1999; Mautone & Mayer, 2007; Naumann, Richter, Flender, Christmann, & Groeben, 2007; Ozcelik, Arslan-Ari, & Cagiltay, 2010). The signaling effect also affects cognitive load (Richter et al., 2018; Song & Bruning, 2016). A meta-analysis conducted by Schneider, Dyrna, Meier, Beege, and Rey (2018a,b,c) showed that cognitive load was significantly reduced by the inclusion of signaling techniques.

4.3. Research question three (characteristics of research)

RQ3. What are the characteristics of multimedia learning research about cognitive load?

- number of articles published by year
- number of articles published by journal
- country context
- education level
- learning domain

4.3.1. Published by year

Fig. 2 shows the number of cognitive load articles published from January 2015 to March 2019, presented according to the year of publication (see Fig. 1). The distribution of studies according to year is close (See Fig. 2). The exception is in 2017 when the number was almost halved (n = 14).

4.3.2. Journal

Among the journals that publish articles related to cognitive load in multimedia learning environments, Computers & Education, Educational Technology & Society and Multimedia Tools & Applications are the most popular journals. They are followed by Learning and Instruction, Interactive Learning Environments, Journal of Educational Psychology (5 articles each) with Educational Technology Research and Development (4 articles), British Journal of Educational Technology, Anatomical Sciences Education, and Instructional Science (3 articles each). One or two articles were published in journals not included in Table 4.

4.3.3. Country

Most reviewed cognitive load studies on multimedia learning were conducted by researchers in Europe (39.3%), followed by Asia (35.1%), America (22.3%), Australia (2.1%), and Africa (1.1%). Although the studies were conducted in many different countries, they were mostly conducted in Germany (n = 22, Table 5). The many investigations on this subject in Germany (Beege, Schneider, Nebel, Mittangk, & Rey, 2017; Park & Brünken, 2015; Park, et al., 2015; Schneider et al., 2018a; Schneider et al., 2019), and the number of related publications in the last 5 years has brought the country to the forefront. Reviews of eye tracking studies in multimedia learning environments suggest that the results from country to country are similar (Alemdag & Cagiltay, 2018).

4.3.4. Learning domain

Most cognitive load studies in multimedia learning environments conducted thus far have utilized STEM subjects (59.6%). Fewer studies have used subjects representative of social sciences (23.4%), health (14.9%), and humanities (2.12%, See Table 6). In recent years increasing of STEM studies can be considered effective in this number. Most cognitive load articles in STEM fields have been conducted using high school and higher education students as subjects (Acarturk & Ozcelik, 2017; Jan, Chen, & Huang, 2016; Kaheru & Kriek, 2016; Liew, Mat Zin, & Sahari, 2017; Park & Brünken, 2015; Yi, Yang, Pi, Huang, & Yang, 2018). Similarly, reviewed articles about STEM indicated that subjects were selected from high school and higher education levels (McDonald, 2016; Pellas, Kazanidis, Konstantinou, & Georgiou, 2017). Some researchers have called for a focus on STEM subjects in the earlier years of schooling (

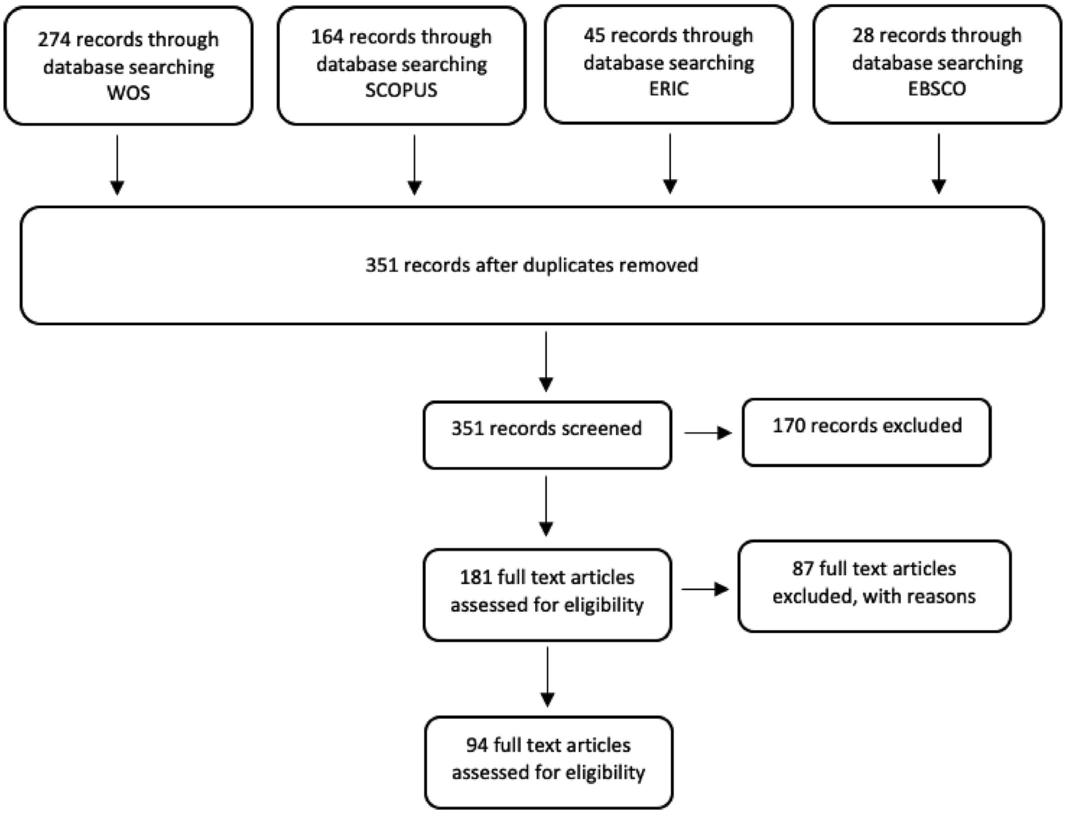

Fig. 1. PRISMA flow diagram (Moher, Liberati, Tetzlaff, & Altman, 2009).

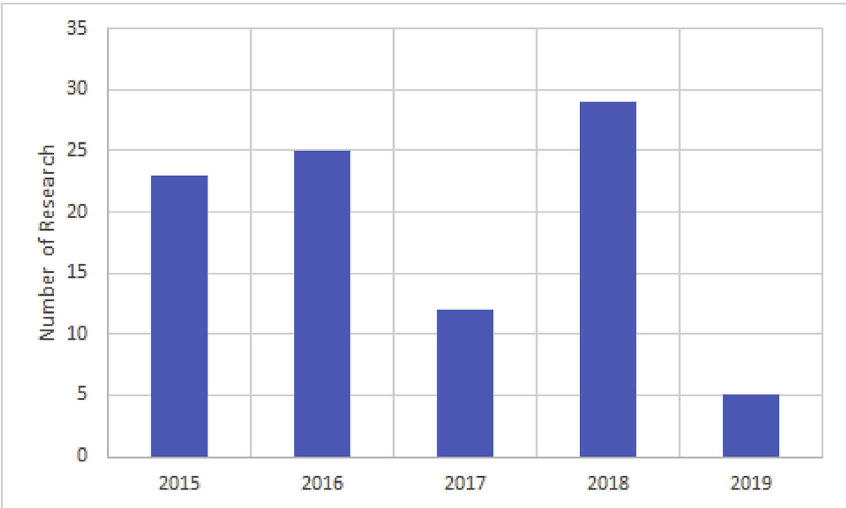

Fig. 2. The distribution of cognitive load research articles on multimedia learning by year.

English & King, 2015).

4.3.5. Education level

Of the 94 studies reviewed, 66 were conducted with higher education students, ten with high school students, nine with secondary school students, three with elementary students, one with both secondary school and higher education students, one with both higher education and high school students, two with Amazon Mturk workers, one with MOOC users, and one with online technical course participants (see Table 7). Higher education students were the primary participant group in the cognitive load in multimedia learning research, similar to that of other research reviews about technology-enhanced learning reports (Alemdag & Cagiltay, 2018; Drysdale,

Table 4
Journals in which cognitive load research articles on multimedia learning were most published.

Journal	Article Numbers
Computers & Education	8
Educational Technology & Society	8
Multimedia Tools and Applications	7
Learning and Instruction	5
Interactive Learning Environments	5
Journal of Educational Psychology	5
Educational Technology Research and Development	4
British Journal of Educational Technology	3
Anatomical sciences education	3
Instructional Science	3

Table 5
Countries that have conducted cognitive load articles on multimedia learning.

Continent	Country	Number of Articles	%
Europe	Germany	22	23.4
	Turkey	7	7.4
	Others	8	8.5
	Total	37	39.3
Asia	Taiwan	16	17.0
	China	6	6.4
	South Korea	6	6.4
	Others	5	5.3
	Total	33	35.1
America	USA	19	34
	Others	2	2.2
	Total	21	22.3
Australia	Australia	2	2.1
Africa	Africa	1	1.1

Table 6
Learning domains used in cognitive load studies of multimedia learning.

Learning Domain	f	%
STEM	56	59.6
Social Science	21	22.3
Health	14	14.9
Humanities	2	2.1
Not mentioned	1	1.1
Total	94	100

Table 7
Education Level of preferred participants in the cognitive load studies of multimedia learning.

Education Level		f	%
Educational Level	Higher Education	66	70.2
	High School	10	10.6
	Secondary school	9	9.6
	Elementary School	3	3.2
	Secondary school + Higher Education	1	1.1
	Higher Education + High school	1	1.1
No Educational Level	Workers from Amazon Mturk	2	2.1
	MOOC users	1	1.1
	Online technical course	1	1.1

Graham, Spring, & Halverson, 2013; G.-J.; Hwang, Wu, & Ke, 2011; J. W. M.; Lai & Bower, 2019; Y.-T.; Sung, Chang, & Liu, 2016; Wu et al., 2012). On the other hand, there are a limited number of studies that have investigated cognitive and multimedia factors utilizing elementary level students and older adult groups. Therefore, there is a need for research on cognitive load and multimedia learning for different types of learners.

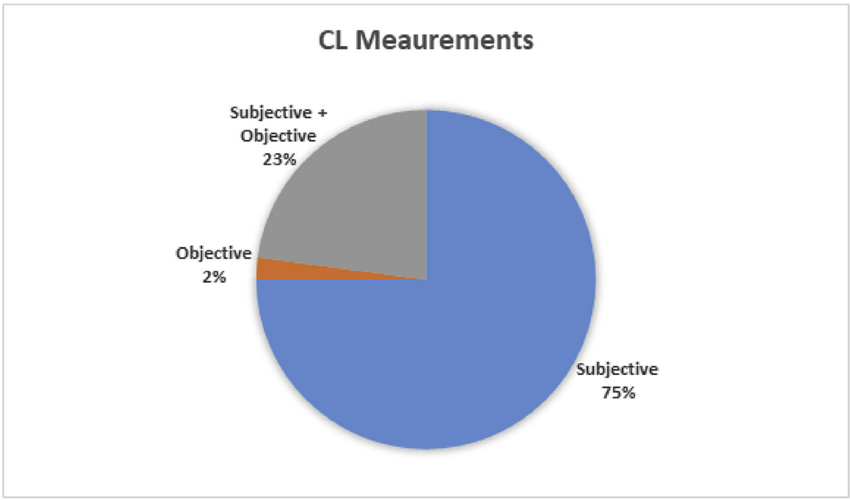

Fig. 3. Types of cognitive load measurements in reviewed articles.

4.4. Research question four (cognitive load measurements)

RQ4. What are the cognitive load measurements used in multimedia learning research?

This review revealed that subjective methods such as scales (e.g., Lin, Lee, Wang, & Lin, 2016) and questionnaires (e.g., Yang, Jen, Chang, & Yeh, 2018) were used in the majority of studies (n = 72) involving the Cognitive Theory of Multimedia Learning between 2015 and 2019 (see Fig. 3). In some studies (n = 22), objective methods such as eye-tracking (e.g., Park et al., 2015), EEG (e.g., Örün & Akbulut, 2019) or fNIRS (e.g., Uysal, 2016) etc. were used to measure cognitive load in addition to subjective methods. Only two review studies (e.g., Uysal, 2016) measured cognitive load by using objective methods alone. These results show that there is a tendency to use subjective methods more often than objective methods to measure cognitive load in multimedia learning research, although objective methods provide more valid and reliable ways to measure cognitive load (Brunken et al., 2003).

Review results show that researchers used various subjective cognitive load measurement tools in their studies. Table 8 presents the most frequent measurement tools in 94 studies. Other tools were excluded from the table because a different subjective measurement tool was used in the studies (e.g., Hwang & Shin, 2018; Lin et al., 2016; Zhang, Zhang, & Yang, 2016). The most frequently used subjective measure was a subjective rating of mental effort (n = 27) developed by Paas (1992) in reviewed articles (e.g., Park et al., 2015; Yang et al., 2018). It consisted of two items: one for task difficulty and the other for mental effort. It is easy to use and was rated on a 9-point Likert scale (Park & Brünken, 2015). While this instrument was used as the major measure for cognitive load alone (e.g., Arslan-Ari, 2018), some researchers adapted the measure and used other tools as well to measure cognitive load (e.g., Yang et al., 2018).

The second most frequently used subjective measure (n = 9) was an instrument developed by Leppink et al. (2013). The original instrument consisted of 10 items to measure intrinsic cognitive load, extraneous cognitive load and germane cognitive load on a 10-point Likert scale. The items included questions such as, “The topic/topics covered in the activity was/were very complex”, “The instructions and/or explanations during the activity were very unclear,” and “The activity really enhanced my understanding of the topic(s) covered.” (Leppink et al., 2013). Four items were adapted for two of the reviewed articles instead of using all of the items

Table 8
Subjective Measures for cognitive load in Reviewed Articles.

Cognitive Load Measurement Tool	f	Sample researches
Subjective ratings of mental effort (Paas, 1992)	27	Park, Korbach, & Brünken, 2015; Yang et al. (2018)
Leppink et al. (2013)	9	Chen & Yen, 2019; Schneider et al. (2019)
Hart and Staveland (1988)	8	Kennedy et al., 2016; Moser and Zumbach (2018)
Paas and Van Merriënboer (1994)	8	Inan et al., 2015; Kizilcec, Bailenson, and Gomez (2015)
Not Mentioned	8	Skuballa, Fortunski, and Renkl (2015)
Cierniak et al. (2009)	4	Efendioğlu, 2016; Jung, Kim, & Na, 2016;
Leppink, Paas, van Gog, van der Vleuten, and van Merriënboer (2014)	4	Chen & Yen, 2019; Schneider, Nebel, Beege, & Rey, 2018c;

Table 9
Objective measures for cognitive load in reviewed articles.

Objective cognitive load measurement	2015	2016	2017	2018	2019	Total	Sample research
Eye-tracking	4	1	1	4	1	11	Park, Korbach, & Brünken, 2015
Time-on-task	3	2	0	6	0	11	Richter et al. (2018)
Dual task paradigm	1	3	0	0	0	4	Park and Brünken (2015)
EEG	0	1	0	0	2	3	Örün & Akbulut, (2019)
Electro-dermal activity	0	0	0	2	0	2	Eitel, Bender, & Renkl, 2019
fNIRS	1	0	0	0	0	1	Uysal, 2016
Face expression analysis	0	0	1	0	0	1	Hung, Chiang, Huang, and Lin (2017)
Rhythm method	1	0	0	0	0	1	Park and Brünken (2015)
Biotrace	0	0	0	1	0	1	Le, Liu, Deng, and Dai (2018)

(Costley & Lange, 2017; Stark, Malkmus, Stark, Brünken, & Park, 2018).

Another subjective measure, The NASA-Task Load Index (NASA-TLX; Hart & Staveland, 1988) was used in eight studies (e.g., Kennedy et al., 2016; Moser & Zumbach, 2018). It consists of six dimensions (mental demand, physical demand, temporal demand, performance effort, and frustration level), and the items were rated on an 18-point Likert scale (Park & Brünken, 2015). A Mental Effort Rating Scale developed by Paas and Van Merriënboer (1994) was used in eight reviewed articles to measure cognitive load (e.g., Inan et al., 2015; Kizilcec et al., 2015). This instrument requires subjects to report difficulty they experience or mental effort they invest with numerical values (Park & Brünken, 2015). Although the details of cognitive load measure(s) were reported in the majority of reviewed studies, researchers did not mention details of how or by whom the cognitive load measure(s) was developed in eight reviewed studies (Skuballa et al., 2015).

An instrument developed by Cierniak et al. (2009) was used in four reviewed articles (e.g., Efendioglu, 2016; Jung et al., 2016). The instrument used a six point Likert-type scale and included questions such as, "How difficult was the learning content for you?" to assess intrinsic cognitive load and, "How difficult was it for you to learn with the material?" to assess extraneous cognitive load (Cierniak et al., 2009, p. 138). Researchers used a questionnaire developed by Leppink et al. (2014) in four reviewed studies (Chen & Yen, 2019; Schneider et al., 2018a). The questionnaire consisted of 10 items on an 11-point (0–10) Likert-type scale. Three items assessed intrinsic cognitive load (e.g., "The topics covered during the lesson were very complex"), three items assessed extraneous cognitive load (e.g., "The instructions and explanations during the lesson were very unclear") and four items assessed germane cognitive load (e.g., "The lesson really enhanced my understanding of the topics covered") (Leppink et al., 2014).

Eye-tracking (n = 11) was the most common objective method used to measure cognitive load in reviewed articles, as seen in Table 9 (e.g., Park, Knörzer, Plass, & Brünken, 2015a,b). However, it is an indirect objective method, and the use of eye-tracking to measure cognitive load is still infrequent compared to subjective methods. Another indirect objective measurement used in reviewed articles was a time-on-task (e.g., Richter et al., 2018). As a direct objective measurement, a dual-task paradigm (n = 4) was used in a few studies (e.g., Park & Brünken, 2015). EEG was used in three studies as another direct objective measure as well (e.g., Örün & Akbulut, 2019). Electro-dermal activity (n = 2) was also used as an objective method in reviewed articles (e.g. Eitel et al., 2019). fNIRS (n = 1), face expression analysis (n = 1), rhythm method (n = 1), and Biotrace (n = 1) were other objective methods used in the reviewed studies.

RQ4.1. What are the measurements are used in the reviewed studies beyond cognitive load measures?

Almost all studies (n = 90) examined learning as an indicator of cognitive load in addition to major subjective or objective cognitive load measurements. Table 10 presents the other measures used in the reviewed articles besides the major cognitive load measures. Retention and transfer tests (e.g., Colliot & Jamet, 2018a,b; Craig & Schroeder, 2017) or achievement tests (e.g., H.-Y. Sung, Hwang, & Chen, 2019) were frequently used to assess learning in the reviewed studies. Learning performance tests were also used in a few of the investigations (e.g., Park, Münzer, Seufert, & Brünken, 2016). Nearly half of the reviewed articles examined prior knowledge (n = 47) with other measures (e.g., Park et al., 2015a,b).

Motivation (n = 18) was another measure used in some reviewed articles in addition to cognitive load (e.g., A.-F. Lai et al., 2019).

Table 10
Other measurements in reviewed articles.

Other Measurement Types	f	%	Sample research
Learning	90	95.74	Colliot & Jamet, 2018b; Craig & Schroeder, 2017
Prior knowledge	47	49.09	Park, Korbach, and Brünken (2015b)
bMotivation	18	36.67	Lai, Chen, & Lee, 2019
Mental rotation	9	24.54	Jung et al., 2016;
Working-memory capacity	8	32.59	Park and Brünken (2015)
Paper folding	6	18.41	Park et al. (2015b)
Perceptions	5	27.16	Lin and Yu (2017)
Self-concept & interest	5	18.41	Richter et al. (2018)
Reading comprehension	4	21.73	Richter et al. (2018)
Cognitive - Learning Styles	3	13.81	Yang (2016)

Table 11
Dependent variables of Cognitive Load Researches on Multimedia Learning.

Dependent Variables	Sub-variables	f	Sample Research
Cognitive Load	Cognitive Load	71	
	Mental Effort	15	Rop, Schüler, Verkoeijen, Scheiter, & Van Gog (2018)
	Extraneous Cognitive Load	28	Colliot and Jamet (2018b)
	Intrinsic Cognitive Load	14	Stark et al. (2018)
	Germane Cognitive Load	3	Richter, Scheiter, & Eitel; (2018)
	Fixation-Duration	9	Zander et al. (2017)
	Dwell Time	2	Makransky, Terkildsen, & Mayer, 2019
	Theta-Alpha	3	Dan and Reiner (2018)
	Oxygenation	1	Uysal, 2016
Learning	Learning Outcomes	20	Schneider, Häßler, Habermeyer, Beege and Rey (2018)
	Retention	24	Colliot and Jamet (2018a)
	Transfer	24	Le et al. (2018)
	Comprehension	17	Lee and Mayer (2018)
	Recall	8	Richter et al. (2018)
	Matching	4	Arslan-Ari (2018)
	Learning Performance	17	Chang, Warden, Liang, & Chou, 2018
	Achievement	16	Wu, Hwang, Yang, and Chen (2018)
Other	Time Spent	15	Schneider et al. (2019)
	Difficulty	10	Brom, Dechterenko, Frollova, Starkova, Bromova, & D'Mello (2017)
	Motivation	10	Lai et al. (2019)
	Satisfaction	4	Wang et al. (2019)

Mental rotation (n = 9) and paper folding (n = 6) were used as a measure related to spatial ability assessment in some studies (e.g., Jung et al., 2016; Park et al., 2015a,b). Working memory capacity was also measured in a few studies (n = 8) (e.g., Park & Brünken, 2015). Perception (n = 5), self-concept and interest (n = 5), reading comprehension (n = 4), and cognitive-learning styles (n = 3) were also measured in a few investigations (e.g., C.-C. Lin & Yu, 2017; Richter et al., 2018; H.-Y. Yang, 2016).

4.5. Research question five (dependent variables)

RQ5. What are the investigated dependent variables on cognitive load in multimedia learning research?

Cognitive load was selected as the dependent variable in nearly all of the studies. Learning was the second most commonly preferred dependent variable. A general tendency in the sub variable of cognitive load was mental effort (n = 15). Also, the most preferred cognitive load type was extraneous (n = 28). The second most frequent variable was learning; therefore, we sought to identify the most preferred learning sub variables. Of the 94 studies reviewed in this study, 24 investigated retention and transfer as a variable (See Table 11). A large body of research has shown that multimedia materials facilitate learning retention and transfer (e.g., Beege et al., 2017; Rop et al., 2018; Schneider et al., 2019; J.; Wang, Mendori, & Hoel, 2019). When results of multimedia learning environment studies were examined, it was seen that if multimedia was designed in accordance with multimedia learning principles, retention and transfer of learning performances increase and extraneous cognitive load decreases (Inan et al., 2015; Kozan, Erçetin, & Richardson, 2015; Park & Brünken, 2015; Schneider, Häßler, Habermeyer, Beege, & Rey, 2018c). Learning performance was another variable considered in multimedia learning environments with cognitive load (Chang, Warden, Liang, & Chou, 2018; Wang & Adesope, 2016; Wang et al., 2017). An analysis was performed on learning performance and achievement variables, especially in pre-test/post-test comparison studies (Cheng et al., 2015; Efendioglu, 2016; Wang et al., 2019). Time spent and difficulty were measured with performance in some studies where learning performance was selected as a variable, (Colliot & Jamet, 2018; Hwang & Shin, 2018; Le et al., 2018). These studies differed from those in which learning outcome was chosen as a variable.

Eye tracking and EEG measurements were performed in cognitive load studies in which objective measurements were made (Dan & Reiner, 2018; Park, Knörzer, Plass, & Brünken, 2015). Fixation duration and theta-alpha power variables were frequently discussed in these studies (Makransky, Terkildsen, & Mayer, 2019).

4.6. Research question six (independent variables)

RQ6. What are the investigated independent variables of cognitive load in multimedia learning research?

The majority of reviewed articles refer to type of multimedia (n = 40) as an independent variable, followed by modality (n = 12), and prior knowledge (n = 8, Table 12).

4.6.1. Multimedia types

One criteria for including an investigative report in the present study was that multimedia was used as the learning environment. The review findings indicate that these multimedia environments have been tested according to various design or environmental features. The most common multimedia design variables employed were cueing-signaling (n = 7) and lectures (n = 7), showing a positive impact of cueing or signaling on learning outcomes (Richter et al., 2018; F.; Wang, Li, Mayer, & Liu, 2018). The second most

Table 12
Independent variables of Cognitive Load studies on multimedia learning.

Independent Variables	Sub-variables	f	Sample Research
Materials Type	Materials	40	Lin et al. (2016)
	Lectures	7	Hung, Kinshuk, and Chen (2018)
	Seductive Details	6	Wang et al. (2017)
	Cueing	5	Jamet and Fernandez (2016)
	Emotion	5	Knörzer, Brünken, and Park (2016)
	Control	4	Chen and Yen (2019)
	Pedagogical Agent	3	Liew et al. (2017)
	Signaling	3	Song and Bruning (2016)
Modality	Modality	12	Lee and Mayer (2018)
Prior Knowledge	Prior Knowledge	8	Richter et al. (2018)
Cognitive Style	Working Memory Capacity	4	Lehmann, Goussios, and Seufert (2016)
	Visual Verbal Cognitive Style	3	Wang et al. (2019)
	Spatial Ability	2	Castro-Alonso, Ayres, Wong, and Paas (2018)
	Cognitive Load	2	Feldon et al. (2018)

frequently studied independent variable was lecture (n = 7). The effects of lecture diversity on cognitive load were also investigated in reviewed articles (Costley & Lange, 2017; Kizilcec et al., 2015; Lee & Mayer, 2015).

4.6.2. Modality

Modality was the second most studied independent variable in reviewed articles (n = 12). These studies demonstrated the effect of modality on cognitive load and learning (Chen & Yen, 2019; Leahy & Sweller, 2016; Lee & Mayer, 2018). The modality effect or principle assumes that when written verbal information accompanies visual information like visual-only presentations, it might cause cognitive load. In the modality effect or principle, when the written verbal information is presented with visual information like visual-only presentation, there will probably be cognitive load. For this reason, presentation of the verbal information through the auditory channel is better when there is corresponding visual information like audiovisual presentation (Kozan et al., 2015; Mayer, 2014a,b,c).

4.6.3. Prior knowledge

Another factor affecting cognitive load was prior knowledge; hence, it was selected as independent (n = 8, Jung et al., 2016; Richter et al., 2018) and covariate variables (n = 9; Brom et al., 2017; Park et al., 2016). Prior knowledge was confirmed to play the expected moderating role in these studies.

4.7. Research question seven (cognitive processes)

RQ7. What are the cognitive processes associated with cognitive load measurements in multimedia learning research?

Researchers agree that learners and information characteristics are important factors to consider when designing multimedia learning environments (Bayram & Bayraktar, 2012; Knörzer et al., 2016; Park, et al., 2015). The cognitive characteristics of learners in particular have been addressed in cognitive load studies (Leahy & Sweller, 2016; Park & Brünken, 2015).

Very few of the reviewed articles studied the cognitive process (18 articles). The most frequently selected cognitive characteristic researched was working memory (n = 9), followed by spatial ability (n = 4), and visual and verbal cognitive styles (n = 3, Table 13).

4.7.1. Working memory

Information is stored and manipulated in working memory for a short time before it is stored in long-term memory (Baddeley, 1992). Assumptions of the cognitive load theory are based on limited working memory capacity, and efforts are made to create guidelines for the design of instructional materials that aim to enhance efficient use of the learner's cognitive capacity (Chandler & Sweller, 1991; Sweller, Chandler, Tierney, & Cooper, 1990). Working memory is a frequently studied cognitive processes in multimedia learning within the scope of this theory, (Anmarkrud et al., 2019; Kozan et al., 2015; Lehmann et al., 2016; Skuballa et al., 2015).

Table 13
Cognitive processes are associated with cognitive load studies addressing multimedia learning.

Cognitive Process	f	Sample Research
Working Memory	9	Kozan, Ercetin, & Richardson (2015)
Spatial Ability	4	Castro-Alonso et al. (2018)
Visual and verbal cognitive style	3	Moser and Zumbach (2018)
Learning Style	1	Kizilcec et al. (2015)
Task-irrelevant thinking	1	Schneider, Dyrna, Meier, Beege & Rey, 2018

Table 14
Multimedia learning environments designed in cognitive load studies.

Presentation Material	Material- environment	f	Sum
Computer Software	Computer based learning environment	43	44
	Computer based IDE Software	1	
Web page	Web based learning environment	10	10
E-Textbook	e-textbook in Computer based learning environment	4	4
Animation	animation in 3D virtual environment	1	5
	animation in Computer based learning environment	3	
	animation in web based learning environment	1	
AR	AR application	2	4
	AR application + Computer based learning environment	2	
Video	Video in computer based learning environment and 3D Model	1	18
	video in computer based learning environment	11	
	Video in computer based learning environment + hologram in 3D learning environment	1	
	video in Web Based Multimedia (MOOCs)	3	
	Content Acquisition Podcast	2	
Simulation	Simulation in computer based learning environment	5	6
	Simulator based learning environment	1	
Mobile Application	Computer based multimedia vs. mobile learning based multimedia	1	4
	Multimedia messaging service (MMS) messages	1	
Textbook	textbook	1	1

4.7.2. Spatial ability

Learners' spatial ability plays a crucial role when visual/pictorial elements are used in multimedia learning environments (Höffler, Schmeck, Höffler, Schmeck, & Opfermann, 2013).

Although there are studies indicating no correlation between spatial ability and cognitive load, they have been considered as covariate variables in the reviewed cognitive load articles (Münzer, Seufert, & Brünken, 2009; Park et al., 2016; Seufert, Wagner, & Westphal, 2017). Researchers argue that spatial ability can be improved when an appropriate learning environment is provided (Casey et al., 2008).

4.8. Research question eight (types of the multimedia learning environments)

RQ8. What are the types of the multimedia learning environments?

Participant learning environment was examined in 94 studies. A computer-based learning environment was employed in 69 of the studies, a web-based learning environment was used in 19 studies, a mobile learning environment was utilized two studies, and an augmented reality environment was used in four studies. Additionally, the experimental process was examined in terms of material type used to present content (see Table 14). Content presentation in 44 investigations involved computer software, 10 used a Web page, 18 used video, six used simulations, five used animations, four used mobile applications, four used an e-textbook, four used augmented reality, and one used a textbook.

4.9. Research question nine (focus of research)

RQ9. What is the focus of research on cognitive load in multimedia learning research?

Cognitive load measurement was the main focus in reviewed articles. Hence, multimedia design was the most commonly studied topic (n = 45). In the studies where multimedia design was chosen as the focus of research, the design principles and effects were mostly studied.

The second most preferred focus of research was instructional media type (n = 17). In cognitive load studies, the most studied comparison media type is augmented reality and 3D environments. Presentation format was the third most preferred focus of research (n = 14). The most commonly compared presentation format was visual/auditory. The other most studied focus of research were

Table 15
Focus of research of Cognitive Load studies on multimedia learning.

Focus of Research	f	Sample Research
Multimedia Design	45	Song and Bruning (2016)
Instructional Media Type	17	Lai et al. (2019)
Presentation Format	14	Leahy and Sweller (2016)
Individual Differences	10	Kaheru and Kriek (2016)
Instructional Method	4	Mihalca, Mengelkamp, Schnotz, and Paas (2015)
Task Type	3	Örün & Akbulut, (2019)
Affective Characteristics	3	Huang & Mayer, 2016
Cognitive Characteristics	2	Jan et al. (2016)

individual differences (n = 10), instructional method (n = 4), task type (n = 3), affective characteristics (n = 3), and cognitive characteristics (n = 2, See Table 15). Gender, working memory, and spatial ability were the most focused individual differences.

5. Conclusion

Several multimedia studies have investigated cognitive load as a variable. These studies performed cognitive load measurements in order to understand learners' cognitive processes. The current study presented findings from a systematic review of cognitive load in multimedia learning, surveying 94 articles published between January 2015 and March 2019. The demographic characteristics of the studies were examined in terms of the published year, country, journal, learning domain, and education level. When we looked at the published years, the articles were similar in number compared to the years; in 2017 the number was lower. The most popular journals that published cognitive load articles included Computers & Education, Educational Technology & Society, and Multimedia Tools & Applications. Several reviews of similar topics showed similar journals at the top (Alemdag & Cagiltay, 2018; Nikou & Economides, 2018). The survey showed that Germany contributed more cognitive load-related research than any other country. Alemdag and Cagiltay (2018) found that Germany produced the greatest number of articles in their review study on eye tracking in multimedia learning environments. Park, Brünken, and Schneider addressed the issue of multimedia learning in Germany in a number of articles (Knörzer et al., 2016; Park & Brünken, 2015; Park et al., 2016; Schneider, et al., 2018; Schneider, Nebel, Pradel, & Rey, 2015; Schneider et al., 2019). It is believed that the general inclination to use STEM (Jones et al., 2018; Lai & Bower, 2019; Ostler, 2015) was reflected in cognitive load studies as well. The investigations primarily chose higher education students as participants. Higher education students are preferred as subjects in education studies because they are accessible, and conducting research with them is relatively easy (Crompton & Burke, 2018; Subhash & Cudney, 2018). Focus of research of cognitive load studies conducted between 2015 and 2019 were mostly multimedia design, instructional media type, presentation format, and individual differences.

Multimedia learning principles have been developed on the basis of Cognitive Theory of Multimedia Learning (Mayer, 2014a,b,c). Hence, it is not surprising that studies measuring cognitive load tend to assess multimedia learning principles (Schwan, Dutz, & Dreger, 2018). Among the reviewed articles, the most frequently studied multimedia learning principles included modality principles, seductive details effect, and signaling/cueing principles—the same principles used in previous multimedia learning studies (Alemdag & Cagiltay, 2018; Molina, Navarro, Ortega, & Lacruz, 2018). Computer and web-based learning environments were preferred most often in contrast to multimedia learning environments designed in the reviewed studies.

Cognitive Load Theory suggests that instructional materials affect learners with three independent cognitive load sources (Paas, Renkl, & Sweller, 2003; Paas, et al., 2003): Intrinsic, Extraneous, and Germane Cognitive Loads. It was found that investigations reviewed in the present study mainly measured the extraneous, intrinsic and overall cognitive loads. Germane cognitive load was investigated in a limited number of studies. Apart from these, the most remarkable finding was that the majority of articles did not mention cognitive load type.

The most commonly used methods were subjective in nature; in a few studies, objective methods like eye tracking, EEG, fNIRS, and dual tasks were used to measure cognitive load. The most frequently studied dependent variables with cognitive load were learning outcomes, retention, and transfer. The majority of reviewed articles refer to the type of multimedia as an independent variable, followed by modality and prior knowledge. Very few of the reviewed cognitive load studies evaluated the cognitive process. The most commonly used were cognitive process, working memory, and spatial ability.

This review, which enables to obtain a holistic understanding of the research on cognitive load in multimedia learning, is useful for researchers as it helps them to learn about the gaps in the literature.

6. Suggestions for future research

This review identified a number of gaps in cognitive load research relating to multimedia learning. The demographic characteristics of the reviewed studies illustrate that the majority of investigations were conducted with higher education students serving as subjects and the use of STEM materials. Replicating existing studies using different types of learners, learning objectives, and content areas is of importance so that boundary conditions of multimedia principles can be identified (Mayer, 2017). For this reason, there is a need for more research about non-STEM disciplines and other areas. In addition, some researchers have emphasized a focus on STEM in the earlier years of schooling when designing studies (English & King, 2015). When we look at the at the metrics of learning domain (See Table 16), we can say that important to focus on non-STEM areas.

Germany where the cognitive load in multimedia learning research is mostly examined between 2015 and 2019 was the most common country among the distribution of studies on this issue. Therefore, the researchers who would like to join research groups in order to conduct this research topic may think about research groups in Germany. As it is one of the topics that maintains its popularity according to years, cognitive load investigations of multimedia learning have undergone continuous theoretical development with the availability of new data (Sweller et al., 2019).

The reviewed studies examined 11 multimedia principles as factors that could potentially affect cognitive load measurements. These studies discussed how multimedia principles affect cognitive load. The studies focused primarily on the modality principle, seductive detail principle, and signaling/cueing principles. These studies mainly investigated the effects on extraneous load; investigation and comparison of the effects on other cognitive load types are recommended. It was important to present design recommendations to reduce extraneous cognitive load. The use of objective methods in cognitive load measurements made it possible to better explain the effects of multimedia principles. The majority of surveyed investigations that used objective measurements

Table 16
Metrics of focus of research.

Focus of Research	Variables	f
Multimedia Design	Retention	17
	Transfer	13
	Comprehension	12
	Task Completion Time	8
	Fixation Duration	8
	Theta Alpha Band Values	3
Presentation Format	Retention	2
	Transfer	2
	Comprehension	2
	Difficulty	2
Material Type	Achievement	4
	Satisfaction	2
	Motivation	2
Individual Differences	Spatial Ability	2
	Working Memory	2
	Prior Knowledge	2
	Gender	2

contributed new understandings of the theory by investigating the effects of multimedia principles. It is recommended that future studies use objective measurements to investigate the effects of multimedia principles on cognitive load. One of the important findings of the present study relates to cognitive load type. Almost half of the studies analyzed did not mention the type of cognitive load (measure cognitive load type), making it difficult to connect the research results to a theoretical base.

There is a lack of measurement instruments applicable to different aspects of cognitive load: namely intrinsic, extraneous, and germane. It is the main challenge within this framework (Klepsch, Schmitz, & Seufert, 2017). It could be useful to utilize the measurement tools developed by Klepsch et al. (2017) that measure different load types, especially in cases of subjective measurements. Researchers need to realize the importance of relating what cognitive load type is measured in all measurement tools used with subjective and objective techniques. This issue is of importance in terms of interpreting the information related to the theory and forming a unity.

The results of the present study indicate that there is a tendency to use subjective measures more than objective measures to assess cognitive load in multimedia learning research, although objective methods provide more valid and reliable ways to measure cognitive load (Brunken et al., 2003). Future studies may focus on a greater use of objective measures to assess cognitive load in multimedia learning research. However, there are several limitations of objective measures: for example, eye-tracking and physiological measures such as heart rate are related indirectly to cognitive load and cognitive processes (Brunken et al., 2003). fMRI is not effective or practical to use in every educational environment or for complex learning processes (Antonenko et al., 2010; Brunken et al., 2003). fNIRS may be more practical than FMRI, but it is not clear whether fNIRS is as sensitive as fMRI (Fishburn, Norr, Medvedev, & Vaidya, 2014). EEG is used in highly-controlled experiments and it can be preferred to fNIRS or fMRI in cognitive load studies. However, in large samples it can be difficult to interpret collected data accurately based on activated brain areas due to current technical constraints (Antonenko et al., 2010). The data collection process (e.g. using electrode gel) may not be comfortable for participants, and therefore may limit the data collection process (iMotions, 2017). For this reason, both subjective measures and objective measures together may be addressed in future research to ensure reliability and validity. Further research may also examine the differences among several objective measures such as EGG, Biotrace, dual-task paradigm or rhythm method in a comparative study. Additionally, questionnaires and scales assessing different types of cognitive load using several items rather than one or two-item scales can be used or developed to obtain more valid and reliable data for measuring cognitive load with subjective methods.

On the other hand, a few studies focused on working memory, motivation, and spatial ability as control variables in the investigations that objective measures were used. These variables can be used more in the future cognitive load studies. As independent variables, multimedia learning principles, and emotion or emotional design were also used in some of the investigations used objective measures. Seductive details effect was the most examined multimedia principle among the studies, however a few articles examined cognitive load with seductive details effect as an independent variable until now. Each of other principles including coherence, pre-training, redundancy, social cues, and spatial contiguity also were used for one time among the investigations. Therefore, there is a gap in the literature to examine different multimedia learning principles as independent variables while using objective measures in cognitive load studies. Emotional design is an emerging concept in multimedia learning research. In reviewed articles, a few studies focused on emotion or emotional design with using objective measures. Thus, there is a need in the literature to investigate emotional design in cognitive load studies with objective measures.

Studies on cognitive characteristics provide suggestions for multimedia learning environment designs. Therefore, it is important to place more importance on them in future studies.

A limited number of reviewed studies investigated motivation. Motivation is not only important for learning, it is also important for cognitive load because high motivation can result in a temporary increase of working memory capacity (Schnotz, Fries, & Horz, 2009). Mayer (2014a, p. 65) reported that the next conceptual step for Cognitive Theory of Multimedia Learning is to include the role of motivation and metacognition in the theory. Investigation of the details of motivation and metacognition mechanisms through studies on emotional design principles and academic motivation could contribute to the related literature.

The distribution of selected learning environments according to years suggests that interest in video has increased. Surprisingly, mobile environments were not preferred often in the reviewed articles, (4 articles). Given the increasing use of mobile technologies in daily life and educational environments, it is recommended that they be included more often in cognitive load studies. Investigations used 3D learning environments, and learning environments with VR or AR features as learning material were conducted commonly by measuring cognitive load with subjective methods. Only eye-tracking and EEG were used in two studies with 3D and AR learning environments respectively. Thus, more studies are necessary to investigate cognitive load on 3D, VR, and AR multimedia learning environments by using objective measures.

In the reviewed studies, multimedia design, material type, presentation format, and individual differences were the most selected focus of research. In the studies focused on individual differences, the most studied differences are working memory, spatial ability, coding ability, gender, and prior knowledge. Individual differences is an important factor emphasized at every stage of the education process. Individualized learning environments can be developed by analyzing the learner characteristics. It is aimed to develop effective multimedia learning environments that take into consideration the design principles and learner characteristics. Individual differences principle is also among the multimedia learning principles put forward by Mayer (2014a,b,c). Researchers that aim at explaining the relationship between individual differences and cognitive load are advised to investigate the effects of attention, perception, and short-term memory that are effective in multimedia learning process. In the studies examined within the scope of this review, it was found that these cognitive differences were not studied. “Does the mental effort of learners differ significantly according to their attention capacity?” with the example of the research question will reveal new information to support the development of advances.

Multimedia design was the most chosen focus of research because of the inherent features of the theory itself. When looking at the independent variables studied on this issue, we realize the prior knowledge, seductive details, pedagogical agent, personalized format, visual cueing, and signal types. In recent years, there has been a tendency towards emotional design. The most studied dependent variables after the cognitive load were retention (17 articles), transfer (13 articles), comprehension (12 articles), and task completion time (8 articles). Recently, in addition to objective cognitive measurements have increased, the variables fixation duration (8 articles) and band values (3 articles) have been introduced. The metrics related to the results were presented in Table 16.

In the studies selected presentation format as the focus of research, modality (audio-text) was still the most studied format. The most widely used independent variables were prior knowledge, learning style, and user experience. Researchers demanding to study cognitive load in modality may be advised to do a research on the placement of visual - verbal sources on the learning environment.

AR based learning and 3D instructional materials have been used mostly in the studies that conduct cognitive load research on comparison of different multimedia materials. The variables examined in these studies differ from other studies as satisfaction, motivation, attention, and self-efficacy. It was seen that cognitive load studies using such new materials were performed in STEM learning domain. For future cognitive load studies, it may be suggested to study on non-STEM learning domains such as history and geography.

It was seen that the objective measurements in cognitive load studies were mostly used for multimedia design, task type, and material type. In the investigations conducted on multimedia design and presentation format, overall (extraneous, intrinsic, and germane) and extraneous cognitive load types were selected in the most studies. This result is expected when considering the changes in the design can reduce the extraneous cognitive load. Further studies can address the research questions such as “How do the effects of multimedia learning design principles on cognitive load reflect on multimedia learning design?” and “Which cognitive load type does each of multimedia learning principles affect?”

In this review, the types of cognitive load, multimedia learning principles, cognitive load measurements, the investigated dependent and independent variables, cognitive processes, the types of multimedia learning environments, the focus of research and the demographic characteristics of the studies in cognitive load research relating to multimedia learning were examined all together differently from the previous cognitive load reviews in the literature. Further reviews can be conducted with the same perspective of this study. Reviews studies relating to a specific aspect such as cognitive load measurements, a multimedia learning principle, or a particular type of multimedia learning environment can also be conducted on cognitive load in multimedia learning in the future. Additionally, further research can address the results of cognitive load research relating to multimedia learning by synthesizing the results in a meta-analysis study.

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