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Multimodal data indicators for capturing cognitive, motivational, and emotional learning processes: A systematic literature review

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Abstract

This systematic review on data modalities synthesises the research findings in terms of how to optimally use and combine such modalities when investigating cognitive, motivational, and emotional learning processes. ERIC, WoS, and ScienceDirect databases were searched with specific keywords and inclusion criteria for research on data modalities, resulting in 207 relevant publications. We provide findings in terms of target journal, country, subject, participant characteristics, educational level, foci, type of data modality, research method, type of learning, learning setting, and modalities used to study the different foci. In total, 18 data modalities were classified. For the 207 multimodal publications, 721 occurrences of modalities were observed. The most popular modality was interview followed by survey and observation. The least common modalities were heart rate variability, facial expression recognition, and screen recording. From the 207 publications, 98 focused exclusively on the cognitive aspects of learning, followed by 27 publications that only focused on motivation, while only five publications exclusively focused on emotional aspects. Only 10 publications focused on a combination of cognitive, motivational, and emotional aspects of learning. Our results plea for the increased use of objective measures, highlight the need for triangulation of objective and subjective data, and demand for more research on combining various aspects of learning. Further, rather than researching cognitive, motivational, and emotional aspects of learning separately, we encourage scholars to tap into multiple learning processes with multimodal data to derive a more comprehensive view on the phenomenon of learning.

Keywords Cognition · Emotion · Learning · Motivation · Multimodality

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1 Introduction

The socio-cognitive theory posits that learning is an active constructive process in which individuals intentionally seek and process information (Bandura 2001; Pintrich 2000). From this perspective, learning involves the interaction of cognitive, motivational, and emotional processes situated in a learning context (Zimmerman and Schunk 2011). Such processes during learning are not confined to a single individual learner. Learners generally learn in a social context that involves interaction with their peers, teachers, and even parents. Learners are not only responsible for their own cognition, motivation, and emotion, but are also collaboratively responsible for the thoughts, feelings, and actions of others (Hadwin et al. 2017).

Furthermore, learners are active agents in social and technology-mediated settings, interacting with their teachers and peers, various different technologies, and numerous artefacts which are available to them, often in collaborative learning environments (Azevedo et al. 2011). Thus, the quality of learning depends on the complex relationships between the cognitive, motivational, and emotional processes and the external sources surrounding students, such as teachers, peers, and/or technologies tools (Bandura 2001; Miyake and Kirschner 2014). The complexity and reciprocity of learning processes and social factors during learning form a major challenge for the learning sciences in their quest to understand these processes and to find effective and efficient ways to facilitate successful learning. One way for unearthing the complexity of learning processes might be to approach the learning phenomena from a multimodal perspective.

1.1 Multimodality of learning

Multimodality refers to the forms of communication and meaning-making that go beyond spoken or written language (Scollon and Scollon 2009). It includes speech, writing, and "visual, aural, embodied and spatial aspects of interaction and environments" (Jewitt 2013, p. 250). In this sense, scholars refer to learning as a multimodal activity (Ochoa et al. 2016). When learners make meaning alone or together in a learning context, they speak, write, draw figures, use facial expressions, move their bodies to represent and communicate about their meaning, manipulate objects, and make use of these multiple modalities concurrently (Magana et al. 2019; Morales et al. 2003).

For example, learners working together in teams ultimately construct their understanding about different phenomena by discussing and negotiating the meanings they have gathered both from available learning resources and each other through different sensory and communicative modalities (Riquelme et al. 2019; Anastopoulou et al. 2011; Kress 2003). In this regard, multimodal research, which is studying individuals' learning endeavours by gathering and exploring different multimodal data, might help to explain the complex interplay of cognitive, motivational, and emotional processes during the learning process.

1.2 Different forms of multimodal data

The multimodal data gathered from learning settings can be either subjective or objective. Subjective data tells about the traits and aptitudes of learners, their perceptions about a specific learning activity (e.g. Khalifeh et al. 2020), or descriptions about

their mental states during learning (e.g. Bannert et al. 2014). Self-reported questionnaires, learning diaries, and audio-video coding of learners' mental activities are common examples of subjective data (e.g. Farrokhnia et al. 2019). Although self-reported data might reveal learners' stated intentions to learn and their beliefs about themselves as learners, such perceptions often do not match with what is actually happening during learning processes (see Noroozi et al. 2018; Winne 2004; Zimmerman 2008). Furthermore, subjective coding of observation data could also be tainted by the coders' interpretations of observed behaviours (see Zimmerman 2008).

Objective data informs about the observable representations of cognitive and affective events that learners actually perform during learning (Winne 2010). Log traces in digital learning environments, physiological reactions during learning such as heart rate variability, skin conductance, and eye gaze can be considered as objective data types. Several educational researchers have used objective data to infer various cognitive and affective states such as cognitive load (Cranford et al. 2014; Haapalainen et al. 2010), and emotions during learning (Chanel and Mühl 2015; D'Mello 2013; Fairclough et al. 2005).

Although using objective data types alone can capture cognitive or affective states of learners in various learning situations (D'Mello et al. 2017), they have to be contextualized in order to relate them with the learning processes. Such data can be combined with observational data such as audio and video recordings of learning situations (Malmberg et al. 2017) to reveal sequential and temporal dynamics of learners' regulatory processes (i.e., planning, enacting strategies, reflection, adaptation) which indicates how previous small-scale situated adaptations in terms of regulation of situated challenges contribute to large-scale adaptation (Hadwin et al. 2017). Such a combination can significantly extend our current knowledge on the sequential and temporal nature of the complex learning processes (Azevedo et al. 2011; Winne and Hadwin 2013).

However, capturing and analysing multimodal data in learning contexts, along with their facets is not a straightforward process and mostly requires both input tools and analytical tools that are sensitive to both the variability between and the complexity of different data modes (Di Mitri et al. 2019; Flewitt et al. 2009). Thus, it is necessary to use various technologies and tools to gather dedicated multimodal data and then analyse it in sophisticated ways, to better understand the complexity of learning in all of its nuances and intricacies.

1.3 Technologies for gathering multimodal data

Digital technologies and advanced educational tools can provide researchers with the possibility to combine subjective and objective data, to trace various cognitive and affective learning processes of the learners, to make micro-level environmental interactions and their responses of the body and brain visible (see Reimann et al. 2014), and to analyse different multimodal data (see Noroozi et al. 2019). In this regard, technologies offer many different opportunities or affordances to both sense and facilitate multimodality in learning (Azevedo and Gašević 2019; Drysdale et al. 2013).

These affordances can be: audible (we can hear sounds in digital environments), visible (we can see objects or people in digital environments), tangible (we can touch or click objects in digital environments), presence-related (we can share the same space with others and/or sense each other's presence (i.e., social presence) in digital environments), temporal (we can be present at the same time with others in digital

environments), reviewable (we can access the messages in digital environments again and again; that is there is a tangible history), and revisable (we can repeatedly update the messages in digital environments) (Kraut et al. 2002). In digital environments, learners typically generate a great amount of cognitive, metacognitive, motivational, and emotional data on what is attended to and studied, in what order this occurs, how much time was spent on what, at what times certain actions occurred, at which places in the study environment, and so forth (Azevedo et al. 2017a, b).

1.4 Research purpose

There is a growing interest in the learning sciences to take advantage of multimodal technologies and techniques to understand the complex relationships within and between individuals and their accompanying motivational and emotional reactions during learning (Blikstein 2013; Jeong et al. 2014; Martin and Sherin 2013; Ochoa et al. 2016). However, to our knowledge, no systematic review has been conducted to provide an overview of the affordances of multimodal data in terms of understanding the cognitive, motivational, and emotional processes during learning. It is not clear what and how data modalities are used to capture cognitive, motivational, and emotional learning processes. As a result, in this paper, we provide an overview of multimodal studies on learning and its underlying processes in order to better understand how to optimally use and combine data modalities when investigating various aspects of learning processes in educational settings.

We review target journal, country of the conducted study, covered subject, participant characteristics, educational level, foci (i.e., cognition, motivation, and/or emotion), type of data modality, research method, type of learning, learning setting, and modalities used to study the different foci (modality-focus). We summarise, analyse, and interpret a comprehensive set of data modalities that are used in combination for measuring various aspects of cognitive, motivational, and emotional learning processes. Specifically, we provide a systematic review of the literature on the type and combination of modalities that have been used for capturing different learning processes by seeking an answer to the following research:

1. What is the current status of data modality studies to investigate learning processes in terms of the target journal, country of the conducted study, covered subject, participant characteristics, educational level, foci, type of data modality, research method, type of learning, learning setting, and modality-focus?
2. What and how are data modalities used to capture cognitive, motivational, and emotional learning processes?

2 Method

A narrative analysis approach (see Noroozi et al. 2012) was used to identify current uses of multimodal data in various fields of learning research and also to address theoretical and methodological implications and avenues for further research. In such a narrative analysis, the aim is to systematically analyse and integrate the state of knowledge in the field and also to highlight areas that research has left unresolved (Van Dinther et al. 2011).

2.1 Search keywords and databases

A list of search keywords was selected based on the most important concepts of the study organised into three concept areas, namely 1) multimodality, 2) learning, and 3) learning facets such as cognition, emotion, and motivation. Upon a first, exploratory search, *multimodal* proved to be quite a generic adjective and caused many irrelevant studies to appear in the search results. The relevant nouns accompanying *multimodal* for the scope of the study were identified to be *data*, *learning analytics*, and *signals*. Additionally, the term *triangulation* was included in that concept area since some relevant papers do not use multimodal in their terminology, but they use triangulation, which implicitly implies multimodality since the triangulation approach can only be achieved by using different data modalities. Using Merriam-Webster's Online, it was decided to include *acquisition* in the learning concept area since, according to the dictionary, they are closely related concepts, and learning is the acquisition of either knowledge or skill.

Once completed, the keywords within concept areas were combined with the Boolean operator OR and the three concept areas with the Boolean operator AND to arrive at the following search strings for Web of Science® and ERIC databases respectively:

- TS = ((“multi*modal data*” OR “multi*modal learning analytics” OR “multi*modal *signal*” OR triangulat*) AND (learn* OR acqui*) AND (cognit* OR emoti* OR motivation* OR collaborat*))
- ((all(“multi-modal data”) OR all(“multimodal data”) OR all(“multi-modal signal”) OR all(“multimodal signal”) OR all(triangulat*)) AND (all(learn*) OR all(acqui*) OR all(cognit*) OR all(emoti) OR all(motivation*) OR all(collaborat*)))

Note that the asterisk (*) wildcard, that replaces multiple characters anywhere in a word, was used to capture all the possible words having the same stem of the keywords of interest. Thus, for example, *cognit** fetches papers with the words cognitive, cognition, and/or cognitions, provided that the other conditions in the search string are met. Note also that although the search strings are quite similar—they actually define the same search—their syntax differs.

An exploratory search for articles was initially conducted on the online repositories of: Education Resources Information Center (ERIC) Digital Library, Web of Science® (WoS), IEEE Xplore®, and SpringerLink®. ERIC was selected as it is the largest repository in education. A quick inspection showed that IEEE and Springer databases produced results that were not in the field of education, and thus out of the scope of the review. Moreover, SpringerLink allows exporting a maximum of 1000 results, while over 2000 results were obtained. So they were excluded from further consideration. The searches on ERIC and WoS were conducted on June 21–22, 2017, resulting in 669 and 318 hits, respectively, totalling 987.

Later, it was noticed that some authors use the term *multichannel* instead of *multimodal*, and therefore, for the sake of completeness, we included *multichannel* in the corresponding concept area. In addition, ScienceDirect® (Elsevier) database was also searched since it contains journals targeting research at the intersection of technical and educational aspects, and thus, with the potential to find more novel data modalities in the field.

On October 3, 2017, the searches were updated on ERIC, WoS, and also ScienceDirect and included for further scrutiny. The updated search yielded 332 results from WoS, while no new results from ERIC were found. Therefore, in the second round, a total of 429 (WoS + ScienceDirect) results were found.

The final keyword searches, for WoS, ERIC and ScienceDirect respectively, were:

- TS = ((“multi*modal data*” OR “multi*modal learning analytics” OR “multi*modal *signal*” OR multi*channel* OR triangulat*) AND (learn* OR acqui*) AND (cognit* OR emoti* OR motivation* OR collaborat*))
- ((all(“multi-modal data”) OR all(“multimodal data”) OR all(“multi-modal signal”) OR all(“multimodal signal”) OR all(multi*channel*) OR all(triangulat*)) AND (all(learn*) OR all(acqui*) OR all(cognit*) OR all(emoti*) OR all(motivation*) OR all(collaborat*)))
- (“multi*modal data*” OR “multi*modal learning analytics” OR “multi*modal *signal*” OR multi*channel* OR triangulat*) AND (learn* OR acqui*) AND (cognit* OR emoti* OR motivation* OR collaborat*)

2.2 Additional search parameters

Using the respective database functionality, various search parameters were specified to narrow down the results to those potentially relevant for this review. The parameters allowed us to refine the document type, language, and year of publication.

To obtain scientific fidelity of the studies, only peer-reviewed publications were included. This implies that other publications such as books, book chapters, dissertations, thesis, conference proceedings, and reports were not included in the analysis because of the lack of information on how the review process had been carried out with these publications. These important and relevant publications were however, consulted in order to shape the theoretical framework of the study and to further accumulate the state of knowledge and specific issues in this field. However, it should be noted that an explicit peer-reviewed option was only available in the ERIC database, while this was not the case in WoS and ScienceDirect. Only published English articles were included in the study since English is the lingua franca of science and the common language of the authors. To study the most recent literature in the field, the time span was limited to publications from 2000 through 2017. This study was not restricted to a single discipline of interest and thus all publications from any domain and/or discipline were included.

2.3 Identification of relevant publications

The results from both the first and second search rounds were then screened. We inspected titles, abstracts, and, when necessary, the full text of the articles and removed a number of irrelevant publications that did not meet the purpose of the study. Publications that were excluded from the further analysis did not: 1) include evidence related to the learning sciences and report at least one of the aspects of learning processes and/or outcomes (i.e., learning cognition, motivation, emotion); 2) use at least two modalities of data (i.e., studies focused only on one data modality); 3) belong

to the formal educational levels such as primary, secondary, high school, college, or higher education (studies conducted in summer-schools, second language courses, distance learning, online courses, and other extra-curricular activities were also included); 4) report empirical findings on the topic such as conceptual, methodological, and theoretical publications. Obviously, duplicate publications were also removed. Additionally, seven publications had to be removed due to the unavailability of the full text, in spite of the efforts made to contact their authors via email and/or ResearchGate®.

Although this systematic review targets empirical studies, we used conceptual and methodological publications to support the results of empirical studies with conceptual literature. Focusing only on the empirical studies could have yielded an incomplete picture of the state of the art of this topic. Therefore, both conceptual and methodological papers were used in the review but not in the analysis to produce an accurate representation of this body of knowledge under a number of research paradigms.

The identification process of relevant publications was carried out by two coders (co-authors) independently for the sake of reliability, resulting in 173 relevant publications included from the first round, and 34 from the second. The number of publications meeting the relevant criteria for the analysis was 207 papers in total.

A checkpoint for inter-rater reliability was set after the classification of the first round of reviewed publications into relevant or not relevant. At this point, the Cohen's Kappa was .40. The coders met to discuss the discrepancies, after which the reliability improved to .68. When processing the second search round, the inter-rater reliability, as measured by Cohen's Kappa was .84. Altogether, the Cohen's Kappa was .61. We then resolved all disagreements and reached consensus through discussion between the coders and also the first author of this study.

3 Results

Applying the systematic search strategy, 207 publications were deemed eligible for inclusion in this review. A complete list of publications is provided in Appendix Table 1, categorised by author(s), target journal, country of the conducted study, covered subject, participant characteristics, educational level, foci, type of data modality, research method, type of learning, learning setting, and modality-focus.

3.1 Results for research question 1

The 207 multimodal publications found in the search were distributed among 139 journals. About a quarter (25.2%) of the included publications came from journals that had two or more multimodal publications, while almost three quarters (74.8%) came from journals that resulted in only one multimodal publication. The journals System (nine cases), Recall (seven), English Language Teaching (six), BMC Medical Education (six), Computers in Human Behavior (four), Computers and Education (four), International Journal of Science Education (four), and Nurse Education Today (four) were on top of the list of the publication outlets due to their vast coverage of the focal point of this research. The remaining publications were found in different journals of various fields ranging from soft sciences such as Teaching and Teacher Education, International Journal of Research in Education

and Science, Education & Training to hard sciences such as School Science and Mathematics.

About 26% of the multimodal publications were published within the subject of language studies focusing on different aspects of second language acquisition. The second most common category was related to the STEM subjects (18%), such as mathematics and physics. Studies on modality research are used in different curricula both in hard subjects such as mathematics, chemistry, physics, medicine, and biology as well as soft subjects, namely the social sciences (e.g., humanities, psychology, economics). About 15% of the publications did not specify a discipline (see Fig. 1).

The number of participants reported ranged from one to 1384 ($M = 81.00$; $SD = 134.40$), while 17 publications did not specify the number of participants. Multimodal research is not restricted to any continent and is studied across all continents. The majority of multimodal research studies have been conducted in the USA (45 publications) and the UK (18). This is followed by countries such as Taiwan (12), Japan (11), Turkey (nine), Australia (eight), Malaysia (eight), and Hong Kong (eight). Only eight multimodal research studies reported results from at least two countries, which stresses the need for a more multicultural dimension of this field of research.

The educational context of the studies varied. The majority of multimodal research studies (46%) were conducted in a university setting with undergraduate students as the target group. The other popular target group for multimodality research was pupils in primary education (11%) followed by secondary education (7%), high school (4%), graduate-level (3%), and early childhood education (1%). No study was conducted in vocational education. Data from at least two educational levels were reported in 5% of the publications, while 22% of the studies did not specify their educational levels where data were collected (see Fig. 2).

The majority of multimodal research studies (116 publications) used mixed methods to analyse various aspects of cognitive, motivational, and emotional learning processes; only eight studies exclusively used qualitative methods (e.g., interviews and

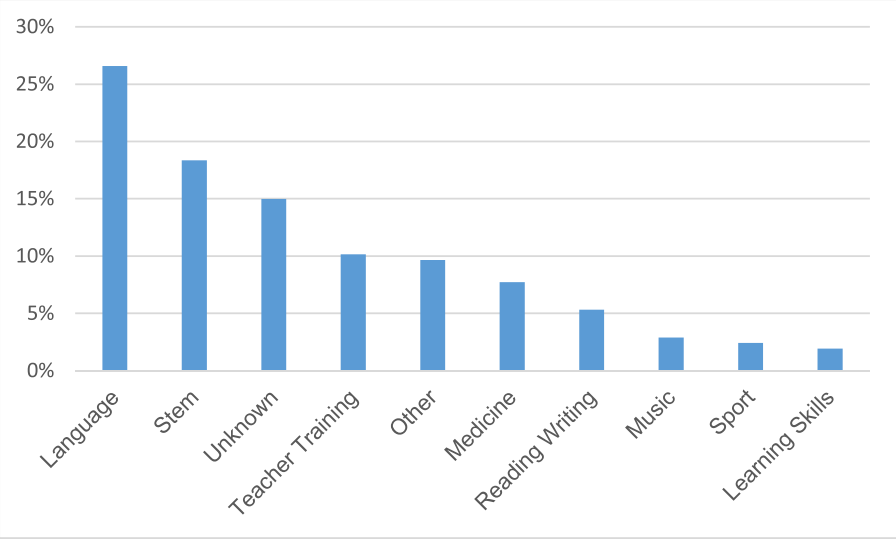

Fig. 1 Distribution of subjects in the studies included in the review expressed in percentages

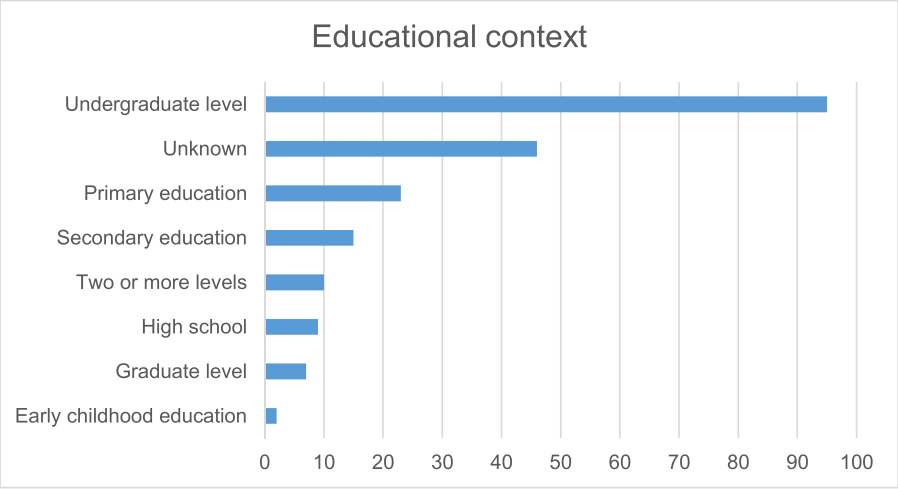

Fig. 2 Educational context of the empirical studies included in the review by number of studies

observations) and 83 exclusively used quantitative methods (e.g., students' products, surveys and performance tests).

When it comes to the type of learning, the findings showed that most of the multimodal publications (84%) focused on individual learning, 11% focused on group learning, and only about 5% of the publications on both individual and group learning. The review shows that multimodal researchers have been mostly investigating individual learning, followed by dyads, triads, small and large groups. For publications on group learning, the group size varied both within and between publications. The minimum size of the learning groups was dyads of learners, and the maximum size of the learning groups was between 20 and 30 members. The group size was fixed for about a quarter (26.3%) of the group learning publications, while in the vast majority of the group learning studies, the group size was not fixed (e.g., 3–4, 3–5, 7–8).

Of the 207 publications, 55% (113) were conducted in the regular (on-campus) setting. About 35% (59 publications) were conducted in the courses offered in the online learning programs. Only three publications (1%) were related to the extra-curricular activities outside the official academic setting. About 10% of publications were conducted in the mixed online and regular setting, while about 12% of studies were categorised within the mixed online and extra-curricular setting. The remaining 2% of studies did not report the learning setting of their study.

3.2 Results for research question 2

Figure 3 displays the distribution of participants per modality. In total, 39,812 participants were observed from 190 of publications that reported about their participants. The survey modality captured the largest number of participants (12,006) followed by an interview (9117), observation (6740), and performance measure (4587) studies. Heart rate variability as an objective modality captured the smallest number of participants with only six participants.

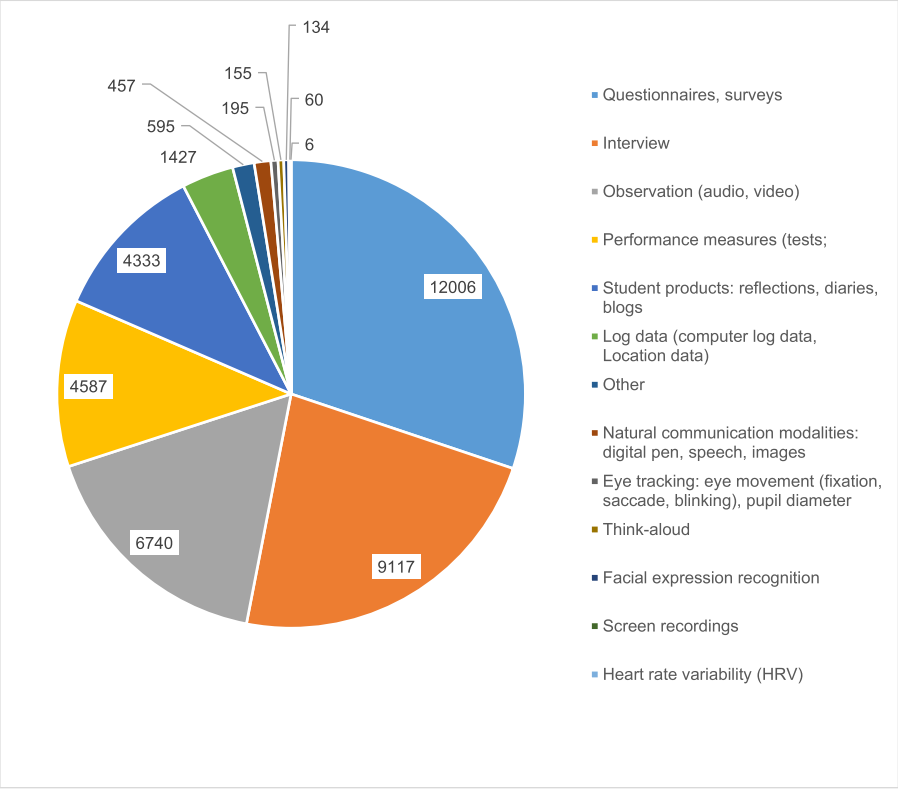

Fig. 3 Distribution of participants per modality

In total, 18 types of modalities were classified in this review. For the 207 multimodal publications, 721 occurrences of modalities were observed. The average number of modalities per publication was 3.48. The maximum number of modalities was seven, and the minimum, as set by the inclusion criteria, was two. Interview, with 182 occurrences, was the favourite modality for data collection. Furthermore, survey (168 occurrences), observation (135), student product (119), and performance measure (47) were the following most frequently used methods of multimodal data collection. The least common modalities were heart rate variability (one occurrence), facial expression recognition (two), and screen recording (four). Figure 4 depicts the type and number of modalities in the reviewed publications.

From the 207 multimodal publications, 98 focused exclusively on the cognitive aspect of learning, followed by 27 that only focused on motivation, while only five papers exclusively focused on the emotional aspects of learning. The remaining publications touched at least two combined aspects of learning. The most frequently studied paired-focus with 46 publications was related to the cognitive and motivational aspects of learning. Only 14 publications touched the cognitive and emotional aspects of learning at the same time. This was followed by seven multimodal publications that studied motivational and emotional learning processes at the same time. Only ten publications focused on cognitive, emotional, and motivational aspects of learning at the same time.

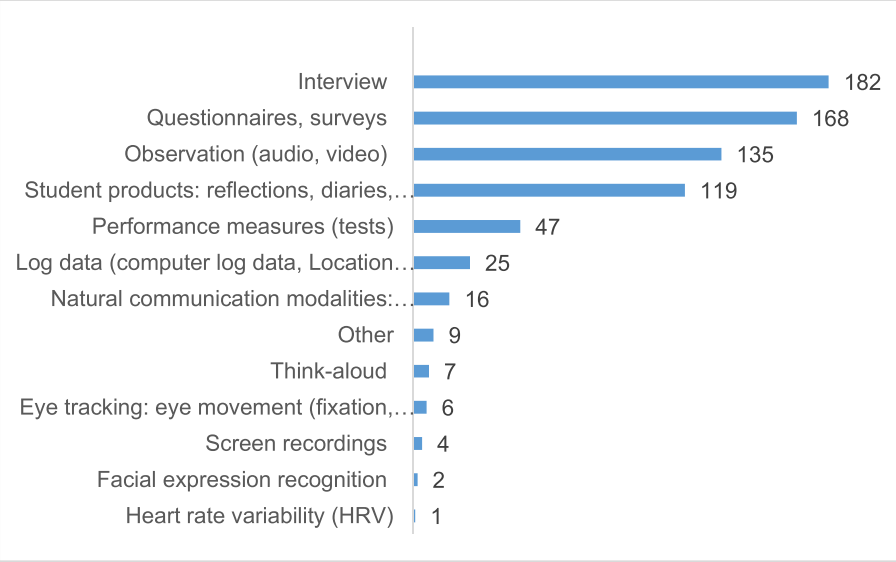

Fig. 4 Modalities used in the empirical studies, the numbers represent the number of studies in which they were used

The focus of each publication in terms of data modalities was paired with different aspects of learning. Out of 721 occurrences of modalities in the reviewed publications, 437 occurrences focused on measuring the cognitive aspect of learning, followed by 203 related to motivation. Only 81 occurrences of modalities were allocated for studying the emotional aspect of learning. Interview, survey, observation, and student product as the most popular data modalities were mostly used to measure cognitive

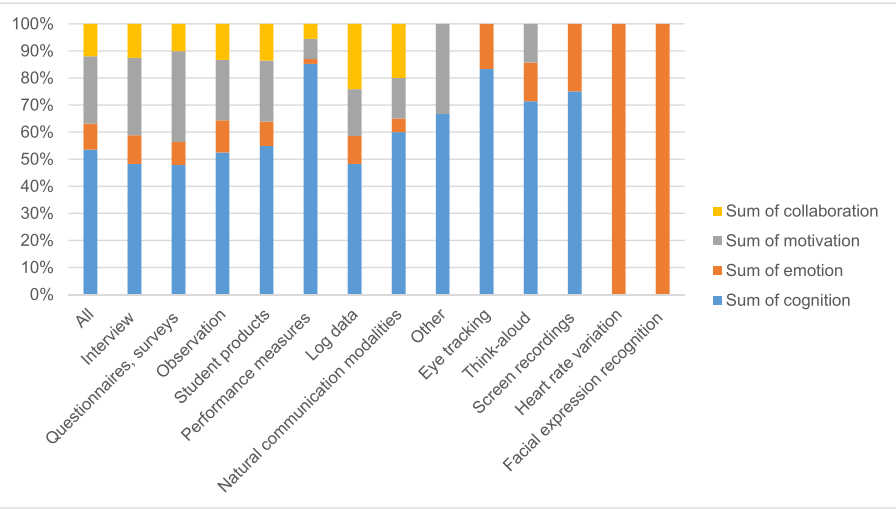

Fig. 5 Distribution of the modalities in terms of different foci expressed in percentages of total number of studies using that modality

aspects of the learning, followed by motivational and emotional aspects (see Fig. 5 for distribution of the modalities in terms of different foci).

The focus of each publication in terms of data modalities was paired with the type of method (i.e., quantitative, qualitative, and mixed) of the multimodal publications. The observation was the main modality used in qualitative studies, while interviews and surveys were the most frequently used methods in quantitative studies. Interview, survey, and performance methods were used in mixed studies (both qualitative and quantitative).

Each publication in terms of the foci of the paper was paired with the type of method of multimodal publications. Qualitative methods were popular to capture cognitive aspects of the learning process, quantitative methods were used for both cognitive and motivational aspects of learning, while mixed-methods captured the combination of cognitive, motivational, and emotional aspects of learning.

The focus of each publication in terms of data modalities was paired with the educational level (ranging from early childhood education to university graduate students) of the multimodal publications. Modalities such as interviews, observation, and performance tests were the most typical type of data collection for lower levels of education (e.g., early childhood, primary, and secondary school). Modalities such as interviews, surveys, observation, and student's product such as reflection reports were the most typical type of data collection for higher levels of education (e.g., high school, undergraduate and graduate university students).

Each publication in terms of the foci of the paper was paired with the educational level of the multimodal publications. No distinctive pattern was found in the foci of the publications for the different levels of education. However, in lower levels of education, the focus was on researching cognitive and motivational aspects of learning, while researchers studied combined cognitive, motivational and emotional aspects of learners mostly in higher levels of education.

The focus of each publication in terms of data modalities was paired with the type of learning setting (i.e., regular, online, and extra-curricular) of the multimodal publications. Modalities such as interviews, surveys, and student products were the most typical types of data collection for the regular learning setting. Modalities such as surveys, observation, and performance tests were the most typical type of data collection for the online learning setting. Modalities such as interviews and observation were the most typical type of data collection for the extra-curricular learning setting in the reviewed publications.

Each publication in terms of the foci of the paper was paired with the type of learning setting (i.e., regular, online, and extra-curricular) of the publications. Cognition was the most frequent focus of the publications for the regular learning setting. In online learning settings, cognition was mostly measured along with either motivational or emotional aspects of learning. No distinctive pattern was found in the foci of the publications for the extra-curricular learning setting. Again, cognitive and motivational aspects of learning in combination were the most frequent focus of the papers for the extra-curricular learning setting.

The focus of each publication in terms of data modalities was paired with the type of learning (i.e., individual, group, and mixed) of the publications. Modalities such as surveys, interviews, and observation were the most typical

type of data collection for individual learning. Modalities such as surveys, interviews, and student products were the most typical type of data collection for the online learning setting. The observation was the most typical modality for the extra-curricular learning setting in the reviewed publications.

Each publication in terms of the foci of the paper was paired with the type of learning of the publications. Cognition was the most frequent focus of publications in all types of learning. In both individual and group learning setting, the emotion was the least touched aspect of learning of the reviewed publications. No distinctive pattern was found in the foci of the multimodal publication when the mixed learning setting was used in the reviewed publications.

4 Discussion

In this systematic review, we aimed to provide an overall picture of the utilisation of multimodal data in learning research. The current review yielded 207 multimodal papers that used more than one data modality to investigate various learning processes. In the following subsections, we elaborate on and synthesise the findings around the research questions.

4.1 Characteristics of multimodal data studies

The findings revealed that the majority of published papers are dispersed across a wide spectrum of different journals ranging from language learning to medical education to educational technology fields. These findings underline the widely distributed and scattered nature of multimodal research. With respect to the methodological issues involved in carrying out multimodal research, there is a need for a multimodal data publication outlet dealing with these issues. Such a journal might help to understand the methodological and analytical skills needed to deal with multimodal data. In addition, such a multimodal journal might act as a venue to develop standard procedures and tools for processing and combining different data modalities in learning research.

The reviewed publications represent all major regions of the world, although North America produced the most. Few studies combined samples from participants from different countries. It seems that multicultural aspects of learning making use of multimodal data is neglected. It is a point of attention since past studies revealed that there might be cultural differences in terms of specifically interpreting emotional cues and motivations (Dekker and Fischer 2008; Eid and Diener 2001; Ekman et al. 1987). For example, Yuki et al. (2007) found that Japanese people focus on the position of the eyes when interpreting emotional expressions, whereas Americans tend to focus on the position of the mouth. Masuda et al. (2008) further found that Japanese people pay attention to the social context (i.e., surrounding individuals' emotions) when interpreting one's emotions whereas Westerners pay less attention to the social context and focus more on the person of interest. Further, a meta-analysis by Dekker and Fischer (2008) revealed significant differences between different societies in terms of academic achievement motivations. Such findings indicate that the motivational and emotional aspects of learning might vary in different cultural contexts. This is particularly important due to the internationalisation of

education. Most educational institutions are melting pots of different cultures in developed countries. Thus, multimodal data collection from multiple cultures might be particularly necessary when investigating the motivational and emotional aspects of learning.

The majority of the multimodal studies were conducted with university students. Further, none of the reviewed publications was conducted in vocational or workplace learning settings. These findings point out the need for widening the sample scope of the multimodal educational research from college settings to other educational institutions for more generalisable inferences. Further, it is known that with the increased use of digital technologies in classrooms, learning in K-12 settings has been become more multimodal (Ryan et al. 2010). Thus, collecting multimodal data from natural classroom settings in lower education levels (e.g. primary and secondary) might open new paths to dive into the experience of K-12 teaching and learning in the digital era. Further, the study showed that health sciences education has been a prominent field that benefited from multimodal data studies. Considering that health sciences are highly focused on skill acquisition through deliberate practices (McGaghie et al. 2014), our findings underline the importance of multimodal data in developing practical and procedural skills of individuals. In this regard, utilising multimodal data in vocational education might also be a promising approach to develop procedural and practical skills of the future blue-collar workforce.

Multimodal data analysis requires the alignment of different analytical methods to process the data coming from different channels. In this regard, multimodal data analysis can also be described as a multi-method approach. The findings of this study support such a conclusion. Our results revealed that the majority of the multimodal research papers used mixed methods and combined quantitative and qualitative methods to derive inferences from the multimodal data.

The findings showed that utilising multimodal data in collaborative learning settings constituted only a small portion of the publications, whereas the majority of the studies focused on individual learning. Indeed, collaborative learning is a more complex phenomenon to investigate than individual learning (Hadwin et al. 2011). This is due to the fact that multiple agents, with their own goals, plans, and strategies, concurrently participate in the group learning activity in collaborative learning influencing each other. When learning collaboratively, students should develop a common understanding and common goals on the learning activity (Dillenbourg 1999; Stahl et al. 2006). Further, they should effectively coordinate their own and other team member's efforts to reach the group's learning goals (Fransen et al. 2013). Thus, a single data channel might fall short of capturing how interactions unfold over time in a collaborative learning setting. In this regard, it is hoped that the use of multimodal data in collaborative learning research will be more prevalent in the future.

In terms of the learning settings, around half of the studies were conducted in regular school environments. Around one-third of the publications were conducted in online learning environments. One specific affordance of online

learning environments is that they might allow researchers to trace learner activities with log data. Nevertheless, our findings showed that few multimodal studies (four papers) in online learning environments used log data. This might be due to two reasons. First, researchers have regarded online environments solely as a learning medium rather than seeing them also as a data channel. Second, online learning environments often used for the learning activity did not allow researchers to collect log data. Considering the first reason, we suggest researchers take advantage of online learning environments for collecting learning traces. A unique attribute of log data collection is that it is unobtrusive and takes place in real-time during learning (Winne 2017). Thus, with log data, it is possible to follow learning events at micro levels without interrupting the learners (see Malmberg et al. 2013). In terms of the second reason, researchers might consider using online environments that facilitate log data collection. Many of today's online learning management systems facilitate time-stamped tracing of learner activities such as resources accessed, assignments completed, discussions attended, and information exchanged with others (Winne 2017).

4.2 What and how are data modalities used to capture cognitive, motivational, and emotional learning processes?

Subjective data (e.g., interviews, self-reports, and observations) were the most prevalent data types in multimodal learning studies. Our findings further showed that subjective data modalities were the most frequent data types used to research all aspects of learning. The use of objective measures such as heart rate variability (one case), facial expression recognition (two cases), screen recordings (four cases), and eye-tracking (five cases) was limited. Heart rate variability was used to complement self-reports, observations, and interview data to understand the anxiety of English language learners. Facial recognition was combined with observations, screen recordings, and log data to infer the emotional states (e.g., boredom, engagement) of learners in intelligent tutoring systems. Screen recordings were matched with observations, interviews, and student artefacts to investigate internet reading strategies, creative thinking strategies, or combined with log data to investigate text search strategies for writing. In one study, screen recordings were also used to investigate how the facial emotions of learners react to the interaction with a virtual tutor. Interestingly, several other objective data types (e.g., electrodermal activity, blood volume pulse, electroencephalogram, temperature, and accelerometer) were not found.

Overall, the existing findings highlight that the use of objective data modalities in learning research is still at infancy. In addition, although the use of physiological measures seems to be on the rise (see Pijeira-Díaz et al. 2016), it seems that they are mostly used alone and not in combination with other data modalities. This is unfortunate because objective measures offer various new venues for learning research. For example, it is known that physiological signals inform on specific cognitive or emotional challenges during learning (Henriques et al. 2013). In this regard, objective data can be combined with

subjective data to explain the sequence of specific micro-level processes that result in particular perceptions, feelings, and other learning-related outcomes. Further, physiological data open new paths to explore social interactions in unique ways. For example, several measures have been developed to measure the physiological (e.g., heart rate variability, electrodermal activity) coupling between interacting individuals (Chanel and Mühl 2015; Palumbo et al. 2017). These measures allow researchers to investigate how the physiological coupling between individuals relate to several interaction features and group performance (Chanel et al. 2012; Henning et al. 2001). The underuse of some objective data in educational settings might also be due to practical limitations. That is, measuring physiological signals in natural classroom settings is more challenging than in laboratory settings. However, as more devices (e.g., smartwatches) are becoming available to measure physiological processes with low intrusiveness (Liao et al. 2012), it can be foreseen that use of objective measures in regular classroom settings will be less challenging in the near future.

The most investigated aspect of the learning process in multimodal studies was cognition. A significant number of publications also focused on motivational aspects of learning. The number of publications investigating emotional aspects of learning was quite low compared with the cognitive or motivational aspects. The under-exploration of emotions in multimodal learning research is also reflected in the limited usage of certain data modalities. For example, facial recognition, electrodermal activity, heart rate variability, blood volume pulse, and body temperature were rarely used though they can be indicative of emotional states in the human mind and body (Henriques et al. 2013). Utilising physiological measures in future learning research might open new paths to increase our knowledge, particularly on the emotional aspects of learning.

More than half of the reviewed publications solely focused on a single aspect of learning, and approximately one third focused on two. According to the general understanding, cognitive, motivational, and emotional processes interact with each other during learning (Zimmerman and Schunk 2011). Thus, learning research should focus on how such interaction among different learning processes unfolds over learning rather than exclusively focusing on the evolution of one single process. Nevertheless, the current results show that cognitive, motivational, and emotional processes have been so far researched in isolation or in dyads rather than learning groups of more than three members. Future research should put more effort into using separate data streams to measure different aspects of learning at the same time, also in collaborative learning settings.

Our findings further indicate that data triangulation in multimodal research has been mostly done with subjective data modalities. It seems that combining self-reports with interviews or observations has been the mainstream triangulation approach. The aim of data triangulation is to provide a comprehensive and multi-perspective understanding of the phenomenon investigated (Boyd 2000). In this regard, complementing subjective with objective modalities would be a better approach to derive less biased inferences and innovative understanding from learning data compared with the triangulation of subjective-only modalities. Multimodal approaches in learning research can help to tackle the constraints of typical single-channel data (e.g., subjective, objective, or

physiological data), and help to draw more valid and reliable inferences about the learning processes (Harley et al. 2015; Pantic and Rothkrantz 2003).

Overall, the findings indicate that cognitive aspects of learning have been studied extensively compared with the motivational or emotional aspects of learning. It was also observed that objective data modalities that can specifically tap into emotional aspects of learning have been largely ignored. Therefore, future research should make use of objective data modalities to extend current knowledge on the emotional aspects of learning. Finally, cognitive, motivational, and emotional aspects of learning have been mostly investigated alone rather than in combination. Future research might utilise different modalities for measuring different aspects of learning to investigate how those aspects are intertwined with each other during learning.

5 Conclusion, limitations and future work

Our findings led to the conclusion that multimodal data is a vast area of research across various learning domains. Comparing the use of multimodal data in various domains is worth investigating in future studies. This would help to understand the affordances and limitations of multimodal data in the whole spectrum of learning domains. Further, multimodal research mostly focused on individual learning. In future studies, collecting multimodal data from collaborative learning settings might help to capture the complex social, motivational, and emotional processes that arise during collaborative learning. Although multimodal data were mostly gathered from on-campus settings, a significant portion of studies collected multimodal data from online or blended learning settings. This highlights the future potential of multimodal data in learning. That is, tracing learning activities with log data and combining those traces with physiological or subjective data might provide new insights on learning in online environments. This study illustrates that multimodal research has mainly benefited from conventional data types such as self-reports, interviews, and observations. Our results plea for including objective data modalities in learning research as well. Particularly, affordances of physiological data in terms of increasing the relatively low number of publications in emotional aspects of learning are worth exploring. Further, rather than researching cognitive, motivational, and emotional aspects of learning separately, we encourage scholars to tap into multiple learning processes with multimodal data to derive a more comprehensive view on the phenomenon of learning. In this case, the use of advanced educational technologies and tools is recommended, especially those tools that facilitate multimodality in learning.

This study has considered those papers studying learning processes with multimodal data, which uses the terms “multimodal” or “multichannel”. However, it must be acknowledged that in some publications, a multimodal approach could have been followed without explicitly using those terms. The current study also bears typical limitations of systematic reviews. It is possible that the search strategies employed, or the databases searched might not have included all the publications that are relevant for our research aims. In addition,

Appendix 1

Table 1 Overview of the various characteristics of the reviewed empirical publications (alphabetically ordered)

Reference	Journal	Country of the conducted study	Subject (discipline)	Number of participant	Educational level (early childhood education, primary, secondary, high school, vocational, undergraduate, graduate)	Focus (cognition, emotion or motivation)
Abubakar & Arshad (2015)	International Education Studies	Nigeria	STEM	15	2	1
Adams (2016)	Canadian Journal of Action Research	Unknown	Teacher training	20	5	1
Afari et al. (2012)	International Journal of Science and Mathematics Education	United Arab Emirates	STEM	90	5	1, 2, 3
Aguaded et al. (2010)	New Educational Review	Spain	Unknown	136	5	2, 3
Agyei & Keengwe (2014)	Education and Information Technologies	Ghana	Other	104	5	1
Aksal et al. (2012)	Eurasian Journal Of Educational Research	UK	Unknown	3	5	1
Allen & Katayama (2016)	System	Japan	Language	54	5	1
Alpay et al. (2010)	European Journal of Engineering Education	UK	STEM	43	5	3
Alton-Lee et al. (2001)	Elementary school journal	New Zealand	Other	17	5	1
Anwaruddin (2013)	Canadian Journal of Action Research	Bangladesh	Language	33	5	3
Arikan & Ozen (2015)	Educational Sciences-Theory & Practice	Turkey	Language	21	1	1, 2
Augustyniak (2014)	International Journal of Music Education	Australia	Music	49	5	1
Aziz et al. (2015)	Malaysian Online Journal of Educational Sciences	Malaysia	Language	11	1	1
	Instructional Science	USA	STEM	75	5	1, 2

Table 1 (continued)

Reference	Journal	Country of the conducted study	Subject (discipline)	Number of participant	Educational level (early childhood education, primary, secondary, high school, vocational, undergraduate, graduate)	Focus (cognition, emotion or motivation)
Balgopal & Montplaisir (2011)						
Basaran & Cabaroglu (2014)	TESL-EJ	Turkey	Language	187	5	1
Basharina (2009)	CALICO Journal	Japan, Mexico, Russia	Language	135	5	1, 3
Berber (2013)	Educational Research and Reviews	Turkey	STEM	245	5	2
Berland et al. (2013)	Journal of Pre-College Engineering Education Research	USA	STEM	159	3	1
Blanton et al. (2001)	Journal of Educational Computing Research	Unknown	Unknown	37	5	1, 3
Borgstrom et al. (2016)	BMC Medical Education	UK	Medicine	107	5	1, 3
Bowman (2017)	Eur. J. Dent. Educ.	UK	Unknown	35	5	1, 2
Brill (2016)	ETR&D	USA	Teacher training	30	6	1
Brown & Melear (2007)	Journal of Science Teacher Education	Unknown	Teacher training	3	5	1
Burton (2017)	Music Education Research	USA	Music	39	1	1
Butz & Stupnisky (2016)	Internet and Higher Education	United States	Unknown	43	6	3
Champagne (2006)	American Journal of Health Education	USA	STEM	12	5	1
Chang & Liu (2016)	System	Taiwan	Language	8	5	1
Chen & Yang (2014)	Language Learning & Technology	Taiwan	Language	15	5	1, 3

Table 1 (continued)

Reference	Journal	Country of the conducted study	Subject (discipline)	Number of participant	Educational level (early childhood education, primary, secondary, high school, vocational, undergraduate, graduate)	Focus (cognition, emotion or motivation)
Chen & Caropreso (2004)	Journal of Interactive Online Learning	USA	Teacher training	70	5	1, 2
Cheng et al. (2015)	Universal Journal of Educational Research	Taiwan	Reading writing	30	0	1
Cheng (2010)	CALICO Journal	USA	Reading writing	3	5	1
Cheng et al. (2012)	Educational Research for Policy and Practice	China	Unknown	30	2	1
Cho (2013)	Reading Research Quarterly	United States	Other	7	3	1
Christian (2017)	Australian Journal of Teacher Education	Australia	Teacher training	51	5	3
Chu et al. (2017)	Internet and Higher Education	Hong Kong	Language	71	5	3
Clark (2013)	International Journal of Music Education	USA	Music	4	3	1, 3
Cook (2008)	International Journal of Science Education	USA	STEM	65	5	1
Cotos (2014)	Recall	USA	Language	31	6	1
Csida & Mewald (2016)	International Journal for Lesson and Learning Studies	Austria	Language	44	1	1
Dalgety & Coll (2006)	International Journal of Science and Mathematics Education	New Zealand	STEM	19	5	3
Daly (2001)	J. Adv. Nurs.	UK	STEM	38	5	1
Dasli (2012)	Language and Intercultural Communication	UK	Language	8	5	1
	BMC Medical Education	UK	Medicine	387	5	1

Table 1 (continued)

Reference	Journal	Country of the conducted study	Subject (discipline)	Number of participant	Educational level (early childhood education, primary, secondary, high school, vocational, undergraduate, graduate)	Focus (cognition, emotion or motivation)
Davies et al. (2012)						
De Villiers (2007)	Journal of Information Technology Education	South Africa	Unknown	43	5	1
Delialioglu & Yildirim (2007)	Educational Technology & Society	Turkey	STEM	25	5	1, 3
Develotte et al. (2005)	Recall	France, Australia	Language	16	5	3
De Witt et al. (2017)	Educational Technology & Society	Malaysia	STEM	31	2	1
De Witt et al. (2013)	Malaysian Online Journal of Educational Technology	Malaysia	STEM	43	2	3
D'Mello & Graesser (2010)	User Model. User-Adapt. Interact.	unclear	Unknown	28	5	2
Dooly & Sadler (2013)	Recall	Spain, USA	Teacher training	43	5	1
Du et al. (2016)	Computers in Human Behavior	United States	Teacher training	9	6	1, 2
Dugartsyrenova & Sardegna (2017)	Recall	USA	Language	8	5	1
Eastwood et al. (2013)	Research in Science Education	Unknown	STEM	95	5	1
Epstein (2008)	Top. Lang. Disord.	USA	Language	7	5	1
Ertmer et al. (2011)	ETR&D	China, Singapore, Taiwan, Australia	Teacher training	346	5	3
Ewald (2005)	Canadian Modern Language Review	Spain	Language	20	5	1

Table 1 (continued)

Reference	Journal	Country of the conducted study	Subject (discipline)	Number of participant	Educational level (early childhood education, primary, secondary, high school, vocational, undergraduate, graduate)	Focus (cognition, emotion or motivation)
Fernandez (2010)	Teaching and Teacher Education	Japan	STEM	18	5	1
Figg & Jamani (2011)	Australasian Journal of Educational Technology	Unknown	Teacher training	2	5, 1	1, 3
Flaspohler et al. (2007)	CBE - Life Sciences Education	USA	STEM	43	5	1
Fook & Sidhu (2015)	Procedia - Social and Behavioral Sciences	USA	Learning skills	181	5, 6	1, 3
Franklin & Hermsen (2014)	Physical Review Special Topics-Physics Education Research	Unknown	Reading writing	1	5	1
Fuchs (2006)	Recall	Germany	Teacher training	34	5	1
Fukuta (2016)	Language Teaching Research	Japan	Language	28	5, 6	1
Gambrell et al. (2011)	Elementary School Journal	USA	Unknown	180	1	3
Garcia & Romero (2009)	Electronic Journal of Research in Educational Psychology	Spain	STEM	43	2	1, 2, 3
Garn et al. (2011)	Physical Education and Sport Pedagogy	United States	Sport	8	2	3
Gavin & Coleman (2016)	Journal of Applied Research In Higher Education	UK	Sport	193	5	3
Ge & Hardre (2010)	Learning Environments Research	Unknown	Unknown	11	6	1, 3
Geluso & Yamaguchi (2014)	Recall	Japan	Language	30	5	1
Gilbert (2012)	Education & Training	Australia	Other	132	5	1, 3

Table 1 (continued)

Reference	Journal	Country of the conducted study	Subject (discipline)	Number of participant	Educational level (early childhood education, primary, secondary, high school, vocational, undergraduate, graduate)	Focus (cognition, emotion or motivation)
Green (2013)	Journal of English for Academic Purposes	UK	Language	3	5	1
Gregersen et al. (2014)	Modern Language Journal	USA	Language	6	5	2
Gruner et al. (2015)	BMC Medical Education	Canada	Other	161	5	1
Gürsoy (2010)	English Language Teaching	Turkey	Language	54	1	1
Hama & Leow (2010)	Studies in Second Language Acquisition	Unknown	Language	34	5	1
Hameen-Anttila et al. (2009)	Health Education	Finland	Medicine	46	1	1, 2
Hargreaves (2015)	Pedagogy, Culture and Society	UK	Other	16	1	2
Herzog (2011)	New Directions for Institutional Research	Unknown	Unknown	543	6	1
Hess & Gunter (2013)	British Journal of Educational Technology	USA	Other	184	5	1, 2, 3
Hewege et al. (2013)	Journal of International Education in Business	Unknown	Other	30	5	1
Hirschinger-Blank et al. (2009)	Journal of Experiential Education	USA	Other	32	5	1
Hodgson et al. (2014)	Assessment & Evaluation in Higher Education	Hong Kong	Medicine	137	5	1
Hommes et al. (2014)	Advances in Health Sciences Education	Netherlands	Medicine	43	5	1
Hong et al. (2008)	International Journal of Science Education	Taiwan	Teacher training	28	1	1, 3
Hosseini & Ghabanchi (2014)	English Language Teaching	Iran	Language	44	5	1
Houtz & Quinn (2006)	Journal of Higher Education Outreach and Engagement	USA	Medicine	84	5	1, 3

Table 1 (continued)

Reference	Journal	Country of the conducted study	Subject (discipline)	Number of participant	Educational level (early childhood education, primary, secondary, high school, vocational, undergraduate, graduate)	Focus (cognition, emotion or motivation)
Hsu et al. (2014)	Journal of Internet Technology	Unknown	Unknown	106	5	1, 2
Huang & Yang (2015)	Journal of Educational Computing Research	Taiwan	Reading writing	36	5	1, 3
Huang (2016)	English Language Teaching	Taiwan	Language	57	5	1, 3
Huang (2013)	Reading Psychology	Taiwan	Reading writing	247	5	3
Ingraham (2014)	TESOL Journal	Unknown	Language	1	1	1
Jain & Sidhu (2013)	Procedia - Social and Behavioral Sciences	Malaysia	Language	60	5	2, 3
Jang et al. (2017)	J. Educ. Comput. Res.	Unknown	Medicine	30	5	1, 2, 3
Järvinen et al. (2007)	Journal of Technology Education	Finland	STEM	12	1, 2	1, 3
Johnson & Howell (2017)	J. Interprofessional Care	Ecuador	Unknown	15	5	1
Kaplan et al. (2011)	Teachers College Record	Israel	Reading writing	1	3	1, 3
Karahan & Roehrig (2015)	Journal of Science Education And Technology	USA	STEM	22	3	1
Kean et al. (2012)	International Education Studies	Japan	Language	15	5	1
Keister & Hansen (2017)	Teach. Learn. Med.	USA	Other	34	5	1
Khalil (2007)	Science Education International	Israel	STEM	91	3	1, 2, 3
Klemola et al. (2013)	Physical Education and Sport Pedagogy	Finland	Sport	17	5	1, 2
Koc (2011)	Teaching and Teacher Education	Turkey		97	5	1, 2, 3

Table 1 (continued)

Reference	Journal	Country of the conducted study	Subject (discipline)	Number of participant	Educational level (early childhood education, primary, secondary, high school, vocational, undergraduate, graduate)	Focus (cognition, emotion or motivation)
			Teacher training			
Koh (2012)	IEEE Trans. Prof. Commun.	Asia-Pacific region	STEM	245	5	1, 2
Ku (2015)	Innovations in Education and Teaching International	Taiwan	Medicine	68	5	1
La Porte (2016)	International Electronic Journal of Elementary Education	USA	Unknown	43	1	3
Lafleur et al. (2015)	Med. Educ.	Canada	Other	40	5	1
Lalor et al. (2015)	Eurasian Journal of Educational Research	Ireland	Unknown	104	5	1
Lawanto et al. (2013)	Int. J. Eng. Educ	USA	STEM	70	5	1
Lawanto et al. (2013)	Journal of STEM Education: Innovations and Research	USA	STEM	97	5	1
Lee (2016)	System	Hong Kong	Language	79	2	1, 3
Lee (2016)	CALICO Journal	Unknown	Language	35	1, 5	1, 3
Leung & Choi (2010)	New Horizons in Education	Hong Kong	Unknown	7	2	1, 2, 3
Lin et al. (2014)	Computers in Human Behavior	Taiwan	Other	8	5	1, 2, 3
Linn & Jacobs (2015)	Journal of Early Childhood Teacher Education	USA	Teacher training	4	5	1
Lo (2009)	Educational Technology & Society	Taiwan	STEM	100	5	1, 3
Lubliner et al. (2009)	Interactive Learning Environments	USA	Unknown	90	5	1
Ma & Cheng (2015)	TESL Canada Journal	Canada	Unknown	12	5	1, 3

Table 1 (continued)

Reference	Journal	Country of the conducted study	Subject (discipline)	Number of participant	Educational level (early childhood education, primary, secondary, high school, vocational, undergraduate, graduate)	Focus (cognition, emotion or motivation)
Mahanin et al. (2017)	International Journal of Research in Education and Science	Brunei	STEM	43	2	1
Malewski et al. (2012)	Teachers College Record	USA	Language	49	5	1, 3
Markic & Eilks (2012)	International Journal of Science Education	Germany	Unknown	180	5	1
Marrongelle (2004)	School Science and Mathematics	USA	STEM	8	5	1
McCoy et al. (2016)	BMC Medical Education	USA	Medicine	108	5	2, 3
McMaster et al. (2015)	Contemp. Educ. Psychol.	unclear	Reading writing	62	5	1
Mellor (2008)	Music Education Research	UK	Music	8	2	1
Meyer & Wurdinger (2016)	Journal of Educational Issues	USA	Other	275	5	1, 3
Mikhaylov & Fierro (2015)	Journal of International Education in Business	Finland, Czech Republic, Ecuador	Language	79	5	1
Miller & Lavin (2007)	Curriculum Journal	Scotland	Unknown	370	1	1, 3
Minelli et al. (2015)	Journal of New Approaches in Educational Research	Catalunya	Teacher training	16	5	2, 3
Miyazoe & Anderson (2012)	Procedia - Social and Behavioral Sciences	Japan	Language	61	5	1, 3
Miyazoe & Anderson (2010)	System	Japan	Language	61	5	1, 3
Miyazoe & Anderson (2010)	System	Japan	Language	23	5	1
Molesworth (2004)	Innovations in Education and Teaching International	UK	Unknown	60	5	3

Table 1 (continued)

Reference	Journal	Country of the conducted study	Subject (discipline)	Number of participant	Educational level (early childhood education, primary, secondary, high school, vocational, undergraduate, graduate)	Focus (cognition, emotion or motivation)
Nathan & Haynes (2013)	Asia-Pacific Journal of Health, Sport and Physical Education	Malaysia	Sport	225	2	1
Navarro & Thornton (2011)	System	Japan	Language	2	5	1, 3
Newsome et al. (2006)	Teachers College Record	USA	Other	43	5	1, 2
Ng (2014)	Computers & Education	Hong Kong	Teacher training	76	5	1, 3
Nyaumwe (2004)	Mathematics Teacher Education and Development	Zimbabwe	STEM	43	5	1
Oga-Baldwin & Nakata (2017)	System	Japan	Unknown	423	1	3
Oh & Steefel (2016)	Nurse Education Today	South Korea	Teacher training	83	5	3
Ohle et al. (2016)	International Journal of Science and Mathematics Education	Germany	STEM	1384	1	1, 3
O'Loughlin et al. (2013)	European Physical Education Review	Ireland	Sport	22	1	1, 3
Osmanoglu (2016)	Educational Research	Turkey	Teacher training	22	5	1
Pachman et al. (2016)	Australasian Journal of Educational Technology	Australia	Learning skills	14	5	1, 2
Park (2012)	Applied Linguistics	USA	Reading writing	17	5	1

Table 1 (continued)

Reference	Journal	Country of the conducted study	Subject (discipline)	Number of participant	Educational level (early childhood education, primary, secondary, high school, vocational, undergraduate, graduate)	Focus (cognition, emotion or motivation)
Parker et al. (2013)	Journal of Attention Disorders	USA	Unknown	19	5	1, 3
Perini et al. (2017)	Comput. Appl. Eng. Educ.	Italy	Other	43	5	1, 3
Pike (2017)	Psychol. Music	USA	Music	9	5	1, 3
Radzi et al. (2013)	Advances in Language and Literary Studies	Malaysia	Language	1	5	1
Ramma et al. (2015)	International Journal of Educational Management	Mauritius	Unknown	27	5, 2	1, 3
Rebuschat et al. (2015)	Studies in Second Language Acquisition	Unknown	Language	52	5	1
Recke Duhart et al. (2016)	Journal of Learning Styles	Mexico	Language	11	5	1, 3
Rianawati (2017)	Journal of Education and Practice	Indonesia	Unknown	36	5	1
Riley (2006)	Technology, Pedagogy and Education	UK	Unknown	29	1	1
Roux et al. (2008)	S. Afr. J. Res. Sport. Phys. Educ. R.	South Africa	Language	274	5	1
Ruiz-López et al. (2015)	Nurse Education Today	Spain	Teacher training	43	5	1, 2, 3
Rule & Harrell (2006)	School Science and Mathematics	USA	STEM	52	1, 5	2, 3
Russell-Bowie (2013)	Australian Journal of Music Education	Australia	Teacher training	197	5	1, 3
Sa'd et al. (2015)	Center for Educational Policy Studies Journal	Iran	Language	60	1	1, 2, 3
Sadideen et al. (2014)	J. Burn Care Res.	UK	Other	12	5	1
Sadler et al. (2004)	International Journal of Science Education	USA	STEM	84	3	1

Table 1 (continued)

Reference	Journal	Country of the conducted study	Subject (discipline)	Number of participant	Educational level (early childhood education, primary, secondary, high school, vocational, undergraduate, graduate)	Focus (cognition, emotion or motivation)
Saez-Lopez et al. (2017)	CulturaY Educacion	Spain	STEM	144	1	3
Salter-Dvorak (2014)	Journal of English for Academic Purposes	UK	Language	Unknown	5	1
Salter-Dvorak (2016)	Teaching in Higher Education	UK	Other	2	5	1
Sami & Ahmad (2015)	JCPSP-J. Coll. Physicians Surg.	Pakistan	Medicine	21	6	2, 3
San Pedro et al. (2014)	International Journal of Artificial Intelligence in Education	Philippines	STEM	126	3	1, 2
Sancar-Tokmak (2013)	Eurasia Journal of Mathematics Science and Technology Education	Turkey	Teacher training	32	5	3
Shadiev & Huang (2016)	Computers & Education	Taiwan, Uzbekistan	Other	10	5	1
Shahamat & Mede (2016)	Education	Turkey	Language	23	1	3
Shahrokni & Talaeizadeh (2013)	TESL-EJ	Iran	Language	115	5	1, 3
Singh et al. (2016)	Turkish Online Journal of Educational Technology - TOJET	Malaysia	STEM	84	2	1, 3
Smith et al. (2016)	Journal of Interactive Learning Research	Unknown	STEM	26	1	1
Smith & Hepworth (2007)	Journal of Librarianship and Information Science	UK	Unknown	43	2	3
Snodin (2013)	Computers & Education	Thailand	Language	28	5	1, 3
Soparat et al. (2015)	International Journal of Research in Education and Science	Thailand	Learning skills	212	5	1
Spence & Tao (2016)	IAFOR Journal of Education	Japan	Unknown	1	1	1

Table 1 (continued)

Reference	Journal	Country of the conducted study	Subject (discipline)	Number of participant	Educational level (early childhood education, primary, secondary, high school, vocational, undergraduate, graduate)	Focus (cognition, emotion or motivation)
Stains & Sevian (2015)	Research in Science Education	USA	Unknown	308	5	1
Stergiou et al. (2009)	International Journal of Medical Informatics	Greece	Medicine	12	5	1, 3
Strijbos et al. (2007)	Computers in Human Behavior	Netherlands	Reading writing	64	5	1, 3
Tanyeli & Kuter (2013)	Eurasian Journal of Educational Research	Unknown	Language	200	5	2, 3
Taub et al. (2017)	Computers in Human Behavior	USA	Reading writing	50	5	1
Tay (2016)	Cogent Education	Unknown	Unknown	420	2	3
Thi Thu et al. (2013)	TESOL Quarterly	Vietnam	Language	419	5	2
Tomas et al. (2011)	Journal of Research in Science Teaching	Australia	Medicine	153	5	1, 2
Tomlinson (2016)	International Journal of Music Education	Australia	Music	1	0	1
Tretter et al. (2006)	Journal of Research in Science Teaching	USA	Other	215	1, 2, 3, 5	1
Tsui & Ng (2000)	Journal of Second Language Writing	Hong Kong	Language	27	2	1, 3
Van Niekerk et al. (2010)	International Journal of Technology and Design Education	South Africa	STEM	3	1	1
Varga-Atkins et al. (2010)	Med. Teach.	UK	Medicine	32	5	1, 3
Vibulphol (2016)	English Language Teaching	Thailand	Language	341	5	3
Vogt (2006)	Recall	Germany, USA, Japan	Other	151	4, 5	1, 2
Wahlgren & Ahlberg (2013)	European Journal of Higher Education	Sweden	STEM	43	5	1

Table 1 (continued)

Reference	Journal	Country of the conducted study	Subject (discipline)	Number of participant	Educational level (early childhood education, primary, secondary, high school, vocational, undergraduate, graduate)	Focus (cognition, emotion or motivation)
Wang et al. (2016)	BMC Medical Education	China	Medicine	10	5	1
Ward et al. (2017)	Journal of Teaching in Physical Education	USA	Teacher training	8	5	1, 3
Webb & Doman (2016)	CATESOL Journal	Macau, China, USA	Language	64	5	1, 3
Wiebe et al. (2009)	Computers & Education	unclear	STEM	33	5	1
Winke et al. (2013)	Modern Language Journal	USA	Language	33	5	1
Wong et al. (2016)	BMC Medical Education	Canada	Medicine	26	5	3
Wong (2014)	English Language Teaching	Hong Kong	Language	43	1	3
Yang & Kim (2011)	System	USA, Philippines	Language	2	5, 6	3
Yang & Chen (2015)	English Language Teaching	Taiwan	Language	115	5	1, 3
Yang & Chung (2009)	British Journal of Educational Psychology	Taiwan	Learning skills	68	3	1
Yap et al. (2016)	Electronic Journal of E-Learning	Malaysia	Unknown	43	5	1, 3
Yau et al. (2016)	Educational Studies in Mathematics	Hong Kong	STEM	43	5	1
Yeo (2001)	Innovations in Education and Training International	Singapore	Reading writing	22	5	1
Zakari et al. (2014)	Nurse Educ. Today	Unknown	Medicine	20	5	1
Zhong (2015)	Nurse Educ. Today	Unknown	Language	2	Unknown	1
Zohoorian (2015)	System	New Zealand	Language	60	5	3

Table 1 (continued)

Reference	Type of modality	Method (qualitative, quantitative, mixed)	Type of learning (individual, collaborative, or mixed)	Learning setting (online, on campus, extracurricular)	Modality->focus
Reference	Type of modality	Method (qualitative, quantitative, mixed)	Type of learning (individual, collaborative, or mixed)	Learning setting (online, on campus, extracurricular)	Modality->focus
Abubakar & Arshad (2015)	1, 10	2	1	2	1->1, 10->1
Adams (2016)	1, 10	2	2	2	1->1, 10->1
Afari et al. (2012)	12, 10, 1, 17	3	1	2	12->2,12->3,17->1,10->2,10->3
Aguaded et al. (2010)	1, 16	2	1	1	1->2,3, 16->2,3
Agyei & Keengwe (2014)	12, 17	2	1	2	12,17->1
Aksal et al. (2012)	1, 10, 16	2	2	1	1->1, 10->1, 16->1
Allen & Katayama (2016)	13, 10, 1	2	2	2	13->1, 10->1, 1->1
Alpay et al. (2010)	12, 17, 18	3	1	2	12->3, 17->3, 18->3
Alton-Lee et al. (2001)	1, 10, 16	2	1	2	1->1, 10->1, 16->1
Anwaruddin (2013)	1, 9, 12, 16, 17	2	2	1	1,12,16->3
Arikan & Ozen (2015)	10, 17	3	1	1	10->1,2, 17->1
Augustyniak (2014)	1, 10, 12	2	1	2	1->1, 10->1, 12->1
Aziz et al. (2015)	1, 10	2	1	2	1,10->1
Balgopal & Montplaisir (2011)	1, 13, 10, 17	3	1	2	1->1, 1->2, 13->1, 13->2, 10->1, 10->2, 17->1
Basaran & Cabaroglu (2014)	1, 10	3	2	2	1->1, 10->1

Table 1 (continued)

Reference	Type of modality	Method (qualitative, quantitative, mixed)	Type of learning (individual, collaborative, or mixed)	Learning setting (online, on campus, extracurricular)	Modality- > focus
Basharina (2009)	10, 12, 16	3	1	1	10- > 1,3, 12- > 1,3, 16- > 1,3
Berber (2013)	10, 12	3	1	2	10- > 2, 12- > 2
Berland et al. (2013)	10, 12, 17	3	1	2	10- > 1, 12- > 1, 17- > 1
Blanton et al. (2001)	1, 12, 16	3	1	1/2	1- > 1,3, 12- > 3, 16- > 1,3
Borgstrom et al. (2016)	13, 12	2	1	2	13- > 1, 13- > 3, 12- > 1, 12- > 3
Bowman (2017)	10, 12	2	1	2	10- > 2, 12- > 1,2
Brill (2016)	1, 12, 16	3	1	1	1- > 1, 12- > 1, 16- > 1
Brown & Melear (2007)	10, 1, 16	2	1	2/3	10- > 1, 1- > 1, 16- > 1
Burton (2017)	17, 1	3	1	2	17- > 1, 1- > 1
Butz & Stupnisky (2016)	10, 12	3	1	1	"10- > 3, 12- > 3"
Champagne (2006)	12, 16	2	1	2/3	12,16- > 1
Chang & Liu (2016)	10, 16	2	1	2	10- > 1, 16- > 1
Chen & Yang (2014)	10, 12, 16	3	2	1	10- > 1,3, 12- > 1,3, 16- > 1,3
Chen & Caropreso (2004)	12, 16	3	1	1	12- > 2, 16- > 1
Cheng et al. (2015)	1, 10, 13, 16	2	2	2	1- > 1, 10- > 1, 13- > 1, 16- > 1
Cheng (2010)	10, 12, 16	2	1	1	10- > 1, 12- > 1, 16- > 1
Cheng et al. (2012)	1, 10, 16	2	1	2/3	1- > 1, 10- > 1, 16- > 1
Cho (2013)	1, 10, 14, 16	3	1	1	1- > 1, 10- > 1, 14- > 1, 16- > 1
Christian (2017)	1, 12	1	1	2	1- > 3, 12- > 3
Chu et al. (2017)	9, 10, 12	3	2	1	9- > 3, 10- > 3, 12- > 3

Table 1 (continued)

Reference	Type of modality	Method (qualitative, quantitative, mixed)	Type of learning (individual, collaborative, or mixed)	Learning setting (online, on campus, extracurricular)	Modality->focus
Clark (2013)	1, 10, 16	2	1	3	1->1,3, 10->1,3, 16->1,3
Cook (2008)	8, 10, 12	3	1	2	8->1, 10->1, 12->1
Cotos (2014)	17, 12	2	1	2	17->1,12->1
Csida & Mewald (2016)	1, 17, 16, 12	2	1	1	1->1, 17->1, 16->1, 12->1
Dalgety & Coll (2006)	12, 10	3	1	2	10->3,12->3
Daly (2001)	11, 17	3	1	2	11->1, 17->1
Dasli (2012)	1, 10	2	1	2	1->1, 10->1
Davies et al. (2012)	12, 10, 9	3	1	1	12->1, 10->1, 9->1
De Villiers (2007)	10, 12, 17	3	1	1	10->1, 12->1, 17->1
Delialioglu & Yildirim (2007)	9, 10	3	1	1	9->1,3, 10->1,3
Develotte et al. (2005)	10, 12, 16	2	2	1/2	10->3, 12->3, 16->3
De Witt et al. (2017)	9, 10, 17	1	2	1	9->1, 10->1, 17->1
De Witt et al. (2013)	10, 12, 16	3	1	1	10->3, 12->3, 16->3
D'Mello & Graesser (2010)	1, 9, 14, 15	1	1	2	1->2, 9->2, 14->2, 15->2
Dooly & Sadler (2013)	1, 16	2	2	1	1->1, 16->1
Du et al. (2016)	1, 10, 16	2	2	1	1->1,2, 10->1,2, 16->1,2
Dugartsyrenova & Sardegna (2017)	1, 9, 10, 12	2	1	1	1->1, 9->1, 10->1, 12->1
Eastwood et al. (2013)	1, 10, 12, 18	3	1	2	1->1, 10->1, 12->1, 18->1

Table 1 (continued)

Reference	Type of modality	Method (qualitative, quantitative, mixed)	Type of learning (individual, collaborative, or mixed)	Learning setting (online, on campus, extracurricular)	Modality->focus
Epstein (2008)	10, 16	2	1	2/3	10->1, 16->1
Ertmer et al. (2011)	10, 12	3	2	1	10->3, 12->3
Ewald (2005)	1, 12, 13	2	2	2	1->1, 12->1, 13->1
Fernandez (2010)	1, 12, 16	2	1	2	1->1, 12->1, 16->1
Figg & Jamani (2011)	1, 10, 12, 16	2	1	1/2	1->1, 10->1,3, 12->1, 16->1
Flaspohler et al. (2007)	12, 16	2	1	2	12->1, 16->1
Fook & Sidhu (2015)	10, 12, 18	2	1	2	10->1,3, 12->1,3, 18->1
Franklin & Hermsen (2014)	9, 13	2	1	2/3	9->1, 13->1
Fuchs (2006)	1, 12, 16	3	2	1	1->1, 12->1, 16->1
Fukuta (2016)	10, 17	3	1	2/3	10->1,17->1
Gambrell et al. (2011)	1, 10, 12	3	1	2	1->3, 10->3, 12->3
Garcia & Romero (2009)	1, 12, 16	3	1	2	1->1,2,3, 12->2,3, 16->1,2,3
Garn et al. (2011)	1, 10, 12	2	1	2	1->3, 10->3, 12->3
Gavin & Coleman (2016)	12, 10, 1	3	1	2	12->1, 10->1, 1->1
Ge & Hardre (2010)	1, 10, 16	2	1	2	1->1, 10->1,3, 16->1,3
Geluso & Yamaguchi (2014)	10, 12, 16	3	1	2	10->1,12->1,16->1
Gilbert (2012)	12, 17	3	1	2	12->3, 17->1
Green (2013)	10, 13, 16	2	1	2	10->1, 13->1, 16->1
	1, 5, 10, 12	3	1	2	1->2, 5->2, 10->2, 12->2

Table 1 (continued)

Reference	Type of modality	Method (qualitative, quantitative, mixed)	Type of learning (individual, collaborative, or mixed)	Learning setting (online, on campus, extracurricular)	Modality->focus
Gregersen et al. (2014)					
Gruner et al. (2015)	10, 12, 17	3	1	1	10->1, 12->1, 17->1
Gürsoy (2010)	1, 10, 12	2	1	2	1->1, 10->1, 12->1
Hama & Leow (2010)	11, 12, 16, 17	3	1	2	11->1, 12->1, 16->1, 17->1
Hameen-Anttila et al. (2009)	1, 10	2	1	1	1->1,2, 10->1,2
Hargreaves (2015)	1, 10, 16	2	1	2	1->2,10->2,16->2
Herzog (2011)	12, 17	1	1	Unknown	12->1, 17->1
Hess & Gunter (2013)	10, 18	3	1	1	10->1,2,3, 18->1
Hewege et al. (2013)	16, 10, 12	2	3	1	16->1, 10->1,12->1
Hirschinger-Blank et al. (2009)	1, 12, 16	3	1	2/3	1->1, 12->1, 16->1
Hodgson et al. (2014)	12, 10, 17	3	2	2	12->1, 10->1, 17->1
Hommes et al. (2014)	1, 10, 12	3	2	2	1->1, 10->1, 12->1
Hong et al. (2008)	17, 10, 1, 12	3	1	3	17->1, 10->3, 12->3, 1->3
Hosseini & Ghabanchi (2014)	16, 17	1	1	2	16->1, 17->1
Houtz & Quinn (2006)	1, 16, 17	3	1	2	1->1,3, 16->1,3, 17->1,3
Hsu et al. (2014)	1, 9, 10, 12, 15, 16, 17	3	1	1	1->1,2, 9->2, 10->1,2, 12->2, 15->2, 16->2, 17->1
Huang & Yang (2015)	12, 10, 17	3	1	1	12->3,10->3,17->1
Huang (2016)	1, 10, 12	3	1	1	1->1, 10->1,3, 12->1,3

Table 1 (continued)

Reference	Type of modality	Method (qualitative, quantitative, mixed)	Type of learning (individual, collaborative, or mixed)	Learning setting (online, on campus, extracurricular)	Modality->focus
Huang (2013)	1, 10, 12	3	1	2	1->3, 10->3, 12->3
Ingraham (2014)	1, 9, 17	3	1	2	1->1, 9->1, 17->1
Jain & Sidhu (2013)	10, 12	3	1	2	10->2,3, 12->2,3
Jang et al. (2017)	9, 11, 12	3	1	1	9->1,2,3, 11->1,2,3, 12->1,2,3
Järvinen et al. (2007)	1, 10, 16	2	1	2	1->1,3, 10->1,3, 16->1,3
Johnson & Howell (2017)	1, 10, 16	2	2	2	1->1, 10->1, 16->1
Kaplan et al. (2011)	1, 10, 16	3	1	2	1->1,3, 10->1,3, 16->1,3
Karahan & Roehrig (2015)	1, 12, 16	3	1	1	1->1, 12->1, 16->1
Kean et al. (2012)	12, 16	3	1	2	12->1, 16->1
Keister & Hansen (2017)	1, 12	3	1	2/3	1->1, 12->1
Khalil (2007)	10, 12, 16	3	1	2	12->3, 16->1,2,3
Klemola et al. (2013)	12, 10	2	2	2	12->1, 12->2, 10->1, 10->2
Koc (2011)	16, 1, 17	2	1	2	16->1, 16->2, 16->3, 1->1, 1->2, 1->3, 17->1, 17->2, 17->3
Koh (2012)	1, 9, 10, 12, 17	3	2	1	1->1,2, 9->1,2, 10->1,2, 12->1,2, 17->1
Ku (2015)	10, 12	3	1	2	12->1
La Porte (2016)	1, 10, 16	2	1	2	1->3,10->3,16->3
Lafleur et al. (2015)	1, 10, 12	3	1	2	1->1, 10->1, 12->1
Lalor et al. (2015)	12, 16, 18	2	1	2	12->1, 16->1, 18->1
Lawanto et al. (2013)	12, 16	3	1	1/2	12->1, 16->1

Table 1 (continued)

Reference	Type of modality	Method (qualitative, quantitative, mixed)	Type of learning (individual, collaborative, or mixed)	Learning setting (online, on campus, extracurricular)	Modality->focus
Lawanto et al. (2013)	12, 16	3	1	1/2	12->1, 16->1
Lee (2016)	17, 16, 10	3	1	2	10->3,16->1,17->1
Lee (2016)	10, 12, 16	3	2	1	10->1,3, 12->1,3, 16->1,3
Leung & Choi (2010)	1, 16	2	1	2	1->1,2, 16->1,2,3
Lin et al. (2014)	1, 10, 12, 17	3	1	1	1->1,2,3, 10->1,3, 12->1,3, 17->1
Linn & Jacobs (2015)	1, 12	3	1	1/2	1->1, 12->1
Lo (2009)	1, 9, 10, 12, 17	2	2	1	17->1, 9,10,12->3
Lubliner et al. (2009)	10, 12, 17	3	1	1	10->1, 12->1, 17->1
Ma & Cheng (2015)	10, 18	2	1	2	10->1,3, 18->1,3
Mahanin et al. (2017)	16, 17	3	1	2	16->1, 17->1
Malewski et al. (2012)	1, 10, 12, 16	2	1	2/3	1->1,3, 10->1,3, 12->1,3, 16->1,3
Markic & Eilks (2012)	12, 16	3	1	2	12->1, 16->1
Marrongelle (2004)	1, 10, 16	2	1	2	1->1, 10->1, 16->1
McCoy et al. (2016)	1, 12	3	2	2	12->2, 12->3, 1->2
McMaster et al. (2015)	1, 12, 16, 17	3	1	2	1->1, 12->1, 16->1, 17->1
Mellor (2008)	1, 10, 14	2	1	2	1->1, 10->1, 14->1
Meyer & Wurdinger (2016)	10, 12	3	1	2	10->1,3, 12->1,3
Mikhaylov & Fierro (2015)	1, 10	2	1	2	1->1, 10->1
Miller & Lavin (2007)	1, 12	3	1	2	1->1,3, 12->1,3

Table 1 (continued)

Reference	Type of modality	Method (qualitative, quantitative, mixed)	Type of learning (individual, collaborative, or mixed)	Learning setting (online, on campus, extracurricular)	Modality- > focus
Minelli et al. (2015)	10, 16	2	1	2	10- > 2, 10- > 3
Miyazoe & Anderson (2012)	10, 12, 16	3	1	1	10- > 1,3, 12- > 1,3, 16- > 1,3
Miyazoe & Anderson (2010)	10, 12, 16	3	2	1	10- > 3, 12- > 3, 16- > 1
Miyazoe & Anderson (2010)	12, 10, 13	3	1	1	12- > 1, 10- > 1, 13- > 1
Molesworth (2004)	1, 12, 16	2	1	1	1- > 3, 12- > 3, 16- > 3
Nathan & Haynes (2013)	1, 10, 16, 17	3	1	2	1- > 1, 10- > 1, 16- > 1, 17- > 1
Navarro & Thornton (2011)	1, 12, 16	2	1	2	1- > 1,3, 12- > 1,3, 16- > 1,3
Newsome et al. (2006)	10, 12, 16	3	1	2	10- > 1,2, 12- > 1,2, 16- > 1,2
Ng (2014)	10, 12, 16	3	1	1	10- > 1,3, 12- > 1,3, 16- > 1,3
Nyaumwe (2004)	10, 12	2	1	2/3	10- > 1, 12- > 1
Oga-Baldwin & Nakata (2017)	12, 1	2	1	2	12- > 3
Oh & Steefel (2016)	10, 12	3	1	2	10- > 3, 12- > 3
Ohle et al. (2016)	1, 12, 17	3	1	2	1- > 1, 12- > 1,3, 17- > 1
O'Loughlin et al. (2013)	10, 12	2	1	2	10- > 1,3, 12- > 1,3
Osmanoglu (2016)	1, 10, 16	2	1	2	1- > 1, 10- > 1, 16- > 1
Pachman et al. (2016)	1, 8, 12, 17	3	1	1	1- > 1,2, 8- > 1,2, 12- > 1,2, 17- > 1
Park (2012)	14, 9, 16	3	1	1	14- > 1, 9- > 1, 16- > 1

Table 1 (continued)

Reference	Type of modality	Method (qualitative, quantitative, mixed)	Type of learning (individual, collaborative, or mixed)	Learning setting (online, on campus, extracurricular)	Modality->focus
Parker et al. (2013)	1, 10, 12, 17, 18	2	1	2/3	1->1,3, 10->1,3, 12->1,3, 17->1, 18->1,3
Perini et al. (2017)	12, 16	3	1	1	12->1,3, 16->1
Pike (2017)	1, 12	2	1	3	1->1,3, 12->1,3
Radzi et al. (2013)	11, 10	2	1	2	11->1, 10->1
Ramma et al. (2015)	1, 10, 12	3	1	2	1->1,3, 10->1,3, 12->1,3
Rebuschat et al. (2015)	10, 11, 12, 17	3	1	2/3	10->1, 11->1, 12->1, 17->1
Recke Duhart et al. (2016)	12, 1, 10	2	1	2	12->1, 12->3, 1->1, 1->3, 10->1, 10->3
Rianawati (2017)	1, 10, 12	3	2	2	1->1, 10->1, 12->1
Riley (2006)	13, 17	3	2	1	13->1, 17->1
Roux et al. (2008)	1, 10, 12	3	1	2/3	1->1, 10->1, 12->1
Ruiz-López et al. (2015)	10, 16	2	1	2	10->1,2,3, 16->1,2,3
Rule & Harrell (2006)	1, 16	3	1	2	1->2,3, 16->2,3
Russell-Bowie (2013)	12, 16	3	1	1/2	12->1, 16->1, 12->3, 16->3
Sa'd et al. (2015)	1, 10, 12/16	2	1	2	1->1,2,3, 10->1,2,3, 12->1,2,3
Sadideen et al. (2014)	10, 12	3	1	2/3	10->1, 12->1
Sadler et al. (2004)	10, 12/16	2	1	2	10->1, 12->1
Saez-Lopez et al. (2017)	10, 12	3	1	1	10->3, 12->3
Salter-Dvorak (2014)	12, 10, 13,	3	1	2	12->1, 13->1, 10->1

Table 1 (continued)

Reference	Type of modality	Method (qualitative, quantitative, mixed)	Type of learning (individual, collaborative, or mixed)	Learning setting (online, on campus, extracurricular)	Modality->focus
Salter-Dvorak (2016)	1, 10, 16	2	1	2	1->1, 10->1, 16->1
Sami & Ahmad (2015)	10, 12	3	1	2/3	10->2,3, 12->2,3
San Pedro et al. (2014)	1, 9	1	1	2	1->2, 9->1
Sancar-Tokmak (2013)	1, 10, 12	3	1	2	12->3
Shadiev & Huang (2016)	10, 12, 16	3	1	1	10->1, 12->1, 16->1
Shahamat & Mede (2016)	1, 16, 17	3	2	2	1->3, 16->3, 17->3
Shahrokni & Talaeizadeh (2013)	9, 13, 10	3	2	1	9->1, 9->3, 13->1, 13->3, 10->1, 10->3
Singh et al. (2016)	10, 12, 17	3	1	2	10->1,3, 12->1,3, 17->1
Smith et al. (2016)	9, 10, 12, 17	3	1	2	9,10,12,17->1
Smith & Hepworth (2007)	10, 12	2	1	2	10->3, 12->3
Snodin (2013)	1, 9, 10, 12, 16	3	1	1	1->1,3, 9->1,3, 10->1,3, 12->1,3, 16->1,3
Soparat et al. (2015)	10, 16	2	1	1	10->1, 16->1
Spence & Tao (2016)	1, 16	2	1	2	1->1, 16->1
Stains & Sevian (2015)	10, 12	3	1	2/3	10->1, 12->1
Stergiou et al. (2009)	1, 10, 12	3	1	1	1->1,3, 10->1,3, 12->1,3
Strijbos et al. (2007)	12, 16, 17	3	2	1	12->3, 16->1,3, 17->1

Table 1 (continued)

Reference	Type of modality	Method (qualitative, quantitative, mixed)	Type of learning (individual, collaborative, or mixed)	Learning setting (online, on campus, extracurricular)	Modality->focus
Tanyeli & Kuter (2013)	12, 10	3	1	2	12->2,3, 10->2,3
Taub et al. (2017)	8, 9	1	1	1	8->1, 9->1
Tay (2016)	1, 10, 12	3	2	1	1->3, 10->3, 12->3
Thi Thu et al. (2013)	10, 16	2	1	2	10->2, 16->2
Tomas et al. (2011)	10, 12, 16	3	1	1	10->1,2, 12->1,2, 16->1
Tomlinson (2016)	1, 10	2	1	2	1->1, 10->1
Tretter et al. (2006)	10, 12, 16	3	1	2	10->1, 12->1, 16->1
Tsui & Ng (2000)	10, 12, 16	3	1	2	10->3, 12->1,3, 16->1
Van Niekerk et al. (2010)	1, 10	2	1	2	1->1, 10->1
Varga-Atkins et al. (2010)	9, 10, 12	2	2	1	9->1, 10->1,3, 12->1,3
Vibulphol (2016)	1, 12	2	1	2	1->3, 12->3
Vogt (2006)	10, 16	2	1	1	10->1,2, 16->1,2
Wahlgren & Ahlberg (2013)	10, 17, 1	2	1	2	10->1, 17->1, 1->1
Wang et al. (2016)	1, 10, 12, 16	3	1	2	1->1, 1->1, 12->1, 16->1
Ward et al. (2017)	1, 10	2	1	2/3	1->1,3, 10->1,3
Webb & Doman (2016)	17, 12, 10	3	1	1	"17->1,12->3"
Wiebe et al. (2009)	1, 8, 17	1	1	1	1->1, 8->1, 17->1
Winke et al. (2013)	8, 10, 12	3	1	2	8->1, 10->1, 12->1

Table 1 (continued)

Reference	Type of modality	Method (qualitative, quantitative, mixed)	Type of learning (individual, collaborative, or mixed)	Learning setting (online, on campus, extracurricular)	Modality->focus
Wong et al. (2016)	10, 12, 16	3	2	2/3	10->3, 12->3, 16->3
Wong (2014)	1, 10	2	1	2	1->3, 10->3
Yang & Kim (2011)	10, 16	2	1	2/3	10->3, 16->3
Yang & Chen (2015)	1, 10, 12, 16	3	1	2	1->1,3, 10->1,3, 12->1,3, 16->1,3
Yang & Chung (2009)	17, 12	3	1	2	17->1,12->1
Yap et al. (2016)	17, 13	3	1	1	17->1, 17->13, 13->1, 13->3
Yau et al. (2016)	1, 10, 16	2	1	2	1->1, 10->1, 16->1
Yeo (2001)	1, 10, 12, 16	3	1	2	1->1, 10->1, 12->1, 16->1
Zakari et al. (2014)	1,10,16	2	1	2	1->1, 10->1, 16->1
Zhong (2015)	1, 10, 16, 17	3	1	2	1->1, 10->1, 16->1, 17->1
Zohoorian (2015)	10,12,16	3	1	2	10->3, 12->3, 16->3

existing review is limited to the studies published in English. Future studies can extend the scope of the findings through the inclusion of non-English publications and searching for terms that might represent multimodality in a wider context than the current study.

Code	**Type of modality**
1	Observation (audio, video)
2	EDA
3	Temperature
4	BVP
5	HRV
6	EEG
7	Accelerometer
8	Eye tracking: eye movement (fixation, saccade, blinking), pupil diameter
9	Log data (computer log data, Location data)
10	Interview
11	Think-aloud
12	Questionnaires, surveys
13	Natural communication modalities: digital pen, speech, images
14	Screen recordings
15	Facial expression recognition
16	Student products: reflections, diaries, blogs
17	Performance measures (tests;
18	Other
Code	**Focus**
1	Cognition
2	Emotion
3	Motivation
Code	**Learning setting**
1	Online
2	On-campus
3	Extracurricular
Code	**Individual or collaborative**
1	Individual learning
2	Collaborative learning
3	Mixed
Code	**Educational level**
0	Early childhood education
1	Primary
2	Secondary
3	High school
4	Vocational (University of applied sciences)
5	Undergraduate
6	Graduate

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Legends for Appendix 1 in terms of type of modalities

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