education sciences

Systematic Review

Motion Capture Systems and Their Use in Educational Research: Insights from a Systematic Literature Review

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Abstract: Motion capture is gaining significance in educational research. Different motion capture systems (MCSs) are used in educational research for different purposes and in different ways, which creates a diversity that is difficult to monitor. The aim of this article is to provide an overview of MCSs and their uses in educational research addressing primary and secondary school education. We conducted a systematic review focusing on the types of MCSs and the concrete systems being used, looking at how they are used, the purposes of their use, the aims and the research questions under investigation, the subjects/topics addressed in the studies, the locations/places of use, the potential benefits of using MCSs perceived by the researchers, and the underlying theories of movement. Based on *n* = 20 studies focusing on primary and secondary school education identified in our database search, we found that these studies mainly used optical MCSs. Furthermore, we identified three main purposes of their use: to directly support the learning process of students, as analysis tools, or for developing tutoring systems that support students in their learning. This paper gives insights into the use of MCSs in educational research and provides a springboard for further research using MCSs in educational research.

Keywords: motion capture; motion capture systems; motion tracking; motion detection; systematic review; education; educational research

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1. Introduction

Raja and Nagasubramani stated that "The era of 21st century is often regarded as an era of technology" [1] (p. 33). Every year, numerous new technological developments find their way into diverse fields of application. Motion capture is one of them [2–5]. Historically, the first systems capturing human motion were developed in the 1970s and 1980s and were used for medical gait analysis [6]. Medicine was not just the first research field for motion capture—it is a field where this technology is still used a lot today (e.g., [2,6]). Since the invention of motion capture systems (MCSs) for medicine, many other disciplines, such as sports science, have adapted MCSs for their interest. However, MCSs are not used exclusively in science. They are important in the gaming industry (e.g., [7,8]) as well. MCSs are known for being part of famous modern game consoles, such as the Xbox 360 developed by Microsoft [9].

A rising number of modern technologies have also begun to be used in primary and secondary education in recent decades in areas such as learning software used on computers, projectors, and cameras [1]. Raja and Nagasubramani [1] highlight that the usage of modern technology leads to more interaction among students and supports their learning process by facilitating the transfer of knowledge. In recent decades, several research projects have focused on the use of MCSs in schools, which demonstrates that MCSs expand the list of technologies used in this setting (e.g., [10–13]). The use of MCSs in educational research is an emerging research area. MCSs are used to investigate different school subjects and topics such as literacy and numeracy [14] and physical activities [10,15], but also different groups of students, for example, school students with intellectual disabilities [14], students with ADHD [16,17], or those who are blind [18].

For other research areas, such as industry and medicine, systematic reviews of the use of MCSs already exist (e.g., [13,19]), but to date there is no detailed overview of different MCSs and their use in educational research. Yet, analyzing and structuring how motion capture is used in the field of educational research, expanding what MCSs are used and in what ways, provides an overview of the research landscape that can be used to identify trends and can provide a springboard for further research in this area. Therefore, the aim of this article is to provide an overview of MCSs and their uses in educational research.

1.1. Motion Capture Systems: Definition and Classifications

Motion capture is often described as a process that includes different steps [6,8,20], for example, as "the process of recording the motion of a subject, processing it on a computer, and mapping it onto a virtual character" [6] (p. 818). In this article, MCSs are understood as those technical systems that are used to record the movements of people.

MCSs can be classified into different subtypes according to their way of tracking movements. Well-known scholars such as Colombo et al. [2], Dower and Langdale [21], Hasler [6], Menache [8], and Nogueira [20] have developed classification systems. Based on these systems, we developed the classification system shown in Figure 1 for this review. It combines the commonly mentioned categories of MCSs that are included in the classification systems by the above-mentioned scholars.

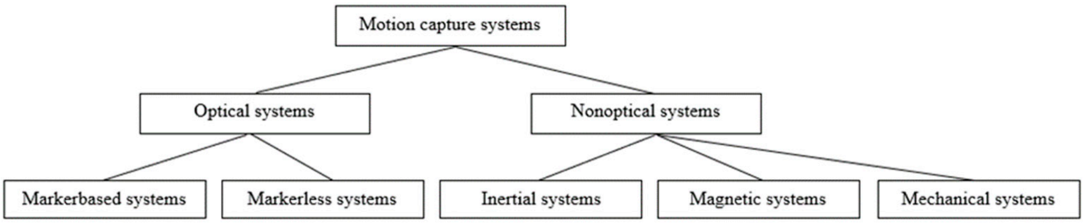

Figure 1. Classification of MCS.

First, we distinguish between optical and nonoptical systems. Optical systems have the shared feature that they use cameras for tracking motion. Optical systems are mentioned in all the classification systems [2,6,8,20,21]. However, all of them also belong to other groups of MCSs that do not use optical tracking but other ways of capturing motion. Following Hasler [6], we grouped these systems as nonoptical systems.

Because most classifications have the category 'markerless systems' and 'markerbased systems', we listed them as further subcategories [2,6,15,21]. The category 'markerless systems' incorporates all systems that do not need markers attached to the tracked person, while marker-based systems use either active or passive markers to detect the human's movements.

Furthermore, most classification systems include magnetic and mechanical systems in their classification [2,6,8,20], which can be seen as important subcategories of nonoptical systems of MCSs. The same applies to the group of systems capturing motion via inertial sensors. This subcategory is listed in most classifications [2,6,21]. Furthermore, some classification systems differentiate between, for example, acoustical and local positioning systems [8,20].

1.2. Previous Research Using Motion Capture Systems in Educational Research

MCSs were not developed for use in educational research. One of the most frequently mentioned research fields is medicine (e.g., [22–25]). Here, MCSs are used in two major areas. First, they are often utilized in the context of diseases associated with the musculoskeletal system, such as dystonia, stroke, and cerebral palsy [23,26,27]. Second, MCSs are occasionally used for research on diseases without direct connection to the musculoskeletal system. For example, Dang et al. [28] used MC in palliative medicine, developing a motion-capture-based avatar for a life review investigation for patients with cancer. Within the field of medicine, MCSs are also used specifically for the rehabilitation of patients with different diseases such as autism, restrictions of the upper limb system, or stroke [19,24,25].

Pintado-Izquierdo et al. [25] point out that video games based on motion capture are not only found in the entertainment industry. Video games are also used in rehabilitation, particularly with stroke patients. Pintado-Izquierdo et al. [25], in their review study, analyzed the effects of video-game-based therapy for supporting the patient's balance and gait compared with conventional therapy. They found that the Nintendo Wii, as an example for marker-based MCSs, and Microsoft Kinect, a markerless MCS, were the predominantly used MCSs for these video games. In ten out of seventeen studies, the balance of the patients improved more when using video games as a rehabilitation tool than in conventional therapy. The video-game-based therapy led to greater improvements in the patients' gaits in three out of six studies. MCSs were not only used for rehabilitation, but also as an analyzing tool for motor functions, for example, for patients with cerebral palsy [23], and for the lower limb system [22,29,30]. An overview of the research interests in the above-mentioned studies suggests that gait analyses of people with different diseases is an important field of use of MCSs within medicine. Examples for the use of MCSs for gait analyses are the studies reviewed by Coca-Tapia et al. [31], which use MCSs to analyze the gait patterns of patients with multiple sclerosis.

A considerable amount of literature has been published on the use of MCSs in sports science. Similar to the research area of medicine, in sports, MCSs are also used for gait analyses. In this line of research, the focus is not on the effects of diseases but on examinations of upper- and lower-limb kinematics [5,7,32]. This is exemplified in the work undertaken by Higginson [32], who reviewed the technology used for running gait analyses and highlights the use of nonoptical MCSs based on inertial sensors, such as accelerometers, in his results. MCSs are used as general analysis tools in various kinds of sports, such as rugby [33], strongman sports [34], and baseball [35]. Edwards et al. [33], for example, compiled the results of previous research on the use of MCSs for analyzing tackle techniques in rugby. In all studies that Edwards et al. analyzed, optical MCSs in the form of passive optoelectronic MCSs were used because they are accurate at measuring large data collection volumes [33].

It is important to mention that the use of MCSs in research is not limited to humans. Different reviews exist regarding the use of MCSs for the movement analysis of animals. Dürr et al. [36] and Serra Bragança et al. [37] analyzed the use of MCSs for investigating the locomotive behavior of insects and horses. Serra Bragança et al. [37] reviewed current research on technologies used for gait analyses in equine orthopedics. Together, the reviewed studies indicated that one technology used for studying horse locomotion is optical MCSs combined with reflective markers. The advantage of optical MCSs highlighted by the authors is that, compared with inertial measurement units, these systems are more accurate "for determining an absolute position" [37] (p. 13).

Similarly, previous studies explored the usage of MCSs in industrial settings. Menolotto et al. [13] reviewed 59 studies on the industrial sector to give an overview of the MCS's usage. Their findings showed that "inertial sensors have been widely employed across all industry sectors (49.2% of the reviewed works)" [13] (p. 5). Furthermore, Menolotto et al. [13] presented that in 30.5% of the studies, camera-based systems were used, and in 10.2%, a combination of inertial and camera-based systems were used. The three industry sectors using MCSs the most were the construction industry, robotics, and automotive and bicycle manufacturing [13]. Today in industrial practice, for example, MCSs are part of simulators. These simulators, in turn, are part of the design and testing process of unmanned aerial vehicles [38].

MCSs are also used in cultural science. Skublewska-Paszkowska et al. [39] explained the use of MCSs as a 3D digital technology for investigating intangible cultural heritage, for example, in studies on arts or in museum studies.

1.3. Aim of This Paper and Research Questions

Even though several reviews exist in the research fields of medicine, sports, animals, industry, and culture, to the best of our knowledge, no systematic review has yet been conducted addressing the use of MCSs in educational research. Therefore, the aim of this article is to provide an overview of MCSs and their use in educational research. We asked the following research questions:

First, we took a closer look at the MCSs, particularly the kinds of MCSs that are used in educational research, asking, (1) what types of MCSs are used in educational research, and which systems specifically are chosen?

Because there are numerous possibilities for using MCSs, we also asked the question (2) how are the MCSs used in the field of educational research? For example, we looked at whether they are used for tracking the whole body, just single parts/joints, or external objects.

In the medical field, MCSs are often used as analysis tools in rehabilitative training, and in the industrial sector, they are used in the process of construction. As these examples of previous research show, there are various purposes for using MCSs. Therefore, we investigated the questions (3) what is the purpose for the use of MCSs in the field of educational research? and (4) what are the aims and research questions of the studies?

In view of the fact that a multitude of topics and subjects are usually investigated in education, in this review, we also investigated the question (5) for which subjects/topics are MCSs used?

Considering that in the context of research and education, different locations of use for MCSs are conceivable and possible, we asked the question (6) in what location/place are MCSs used?

Since it is not yet clear what MCSs can offer for educational research, we investigated how their potential benefits are evaluated by the scholars conducting the studies. We therefore asked (7) what benefits are perceived by researchers using MCSs in their studies?

The use of MCSs is always related to movements. In the field of research, different theorizations of movements are vital. Therefore, we asked the question (8) how do the scholars relate their study to an underlying theory of movement?

2. Materials and Methods

To answer the research questions above, we conducted a systematic literature review. In order to identify relevant research articles, we conducted the search procedure using two scientific databases, Web of Science and PsycInfo. We followed Hjelte et al. [40] in using Web of Science "since we wanted to include high level journals" (p. 3) and added PsycInfo, which also includes high-level journals, to increase the number of articles in our review. All results were screened and analyzed in line with the research questions. With PRISMA [41], Gough et al. [42], and Nilsson et al. [43] in mind, we proceeded in three steps: identification of potential articles through database searches, screening of all articles based on inclusion and exclusion criteria, and analysis of the included articles according to deductively derived categories. The process of conducting our review and its three steps are shown in Figure 2. Each of the steps is described in detail in the following subsections.

2.1. Identification Step

This review addresses education in primary and secondary schools as a central research topic. Therefore, the two databases Web of Science and PsycINFO were selected to identify the articles that contain the most common high-ranking journals in the field of educational research. As search terms, we connected different synonyms for motion capture and education. The search terms used synonymously for motion capture were 'MoCap' OR 'motion cap*' OR 'motion track*' OR 'motion percep*' OR 'motion detect*' OR 'performance cap*'. The first four terms were derived from Hasler [6], who listed them as equivalent words. The other two terms were chosen because they are often used as synonyms for motion capture. For search terms addressing education, we used 'educ*' OR 'school*' OR 'teach*' OR 'learn*' OR 'cogn*'. For the identification process, all synonyms addressing education were connected with all synonyms addressing motion capture to search for articles.

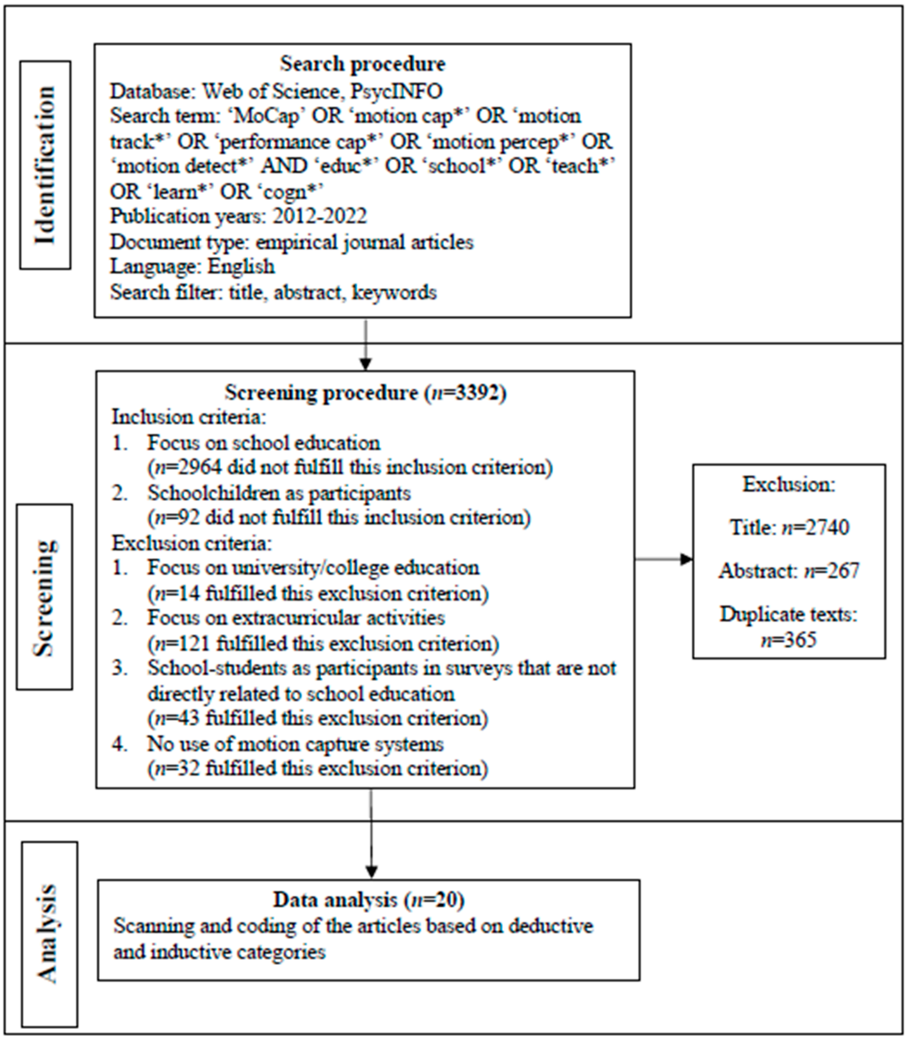

Figure 2. Flow Diagram.

We decided to look for these combinations either in the title, the abstract, or the keywords of the articles. A further limitation was to include only empirical articles published in English. This was because most current scientific articles are written in English and because the researchers conducting this review did not want to include a few other languages based on personal abilities, which would not have been systematic. The last ten years (2012–2022) were set as the search period to ensure that recent articles are included in the analysis and that the results represent the current state of the research field. We conducted the review in February, 2022, so studies from the 10-years interval 2012–2021 as well as in the beginning of 2022 were included. Through this search, 3392 articles were found as results in the databases.

2.2. Screening Step: Inclusion and Exclusion Criteria

To find the articles that were relevant to our research aim and questions, inclusion and exclusion criteria were specified. The following inclusion criteria were defined:

1. Focus on school education: We decided to include only articles that investigated the practical use of MCSs in school education and limited the range of schools to primary,

secondary, and high schools. This ensured that the content focus was on the key aspects of school-based learning.
2. School students as participants: For this review, articles were included where students were the participants of the study. By doing so, we made sure that the included articles described results in which statements were made about the use of MCSs or motion-capture-based programs with school students.

The following exclusion criteria were defined:

1. Focus on university/college education: as a counterpart to the first inclusion criterion, we excluded all articles investigating the use of MCSs in university or college education to avoid investigating the use of MCSs with adults.
2. Focus on extracurricular activities: To restrict the number of results to those with reference to school education, we excluded articles that analyzed MCSs in extracurricular activities. Dancing or playing a musical instrument that does not take place in a school setting but during leisure time are examples specifying 'extracurricular activities'. The term includes activities that may be taught in schools but were not taught in a regular school setting in the context of the article.
3. School students as participants in surveys that are not directly related to school education: Due to the broad range of search terms, the results of the identification step included articles that investigated behaviors or abilities of school-aged children that were not related to education. One example of studies not related to school education is the comparison of the jump kinematics of overweight and normal weight children [44]. By using this exclusion criteria, it ensured a focus on articles exploring educational content.
4. No use of MCSs: Some search terms, such as 'motion percep*' led to results not using MCSs in the investigations. Instead of being connected to MC, the term 'motion percep*' was, for example, connected to the coherent motion perception, evaluated with a psychophysical protocol, of children while reading [45].

2.3. Screening Step: Screening Process

First, before screening all articles, all duplicates were eliminated, which was necessary due to the search in two databases. In total, 365 duplicate texts were sorted out.

With regard to the above-mentioned inclusion and exclusion criteria, we screened the titles and abstracts of all remaining articles (n = 3027). A high number of the identified articles were excluded from the analysis (see detailed information below) due to one or more of the inclusion and exclusion criteria mentioned above. This high number of excluded articles emerged due to a variety of reasons. First, many articles were excluded because the search terms were chosen broadly. Search terms such as 'learn*' or 'cogn*' led to many results including terms such as 'deep learning'. Additionally, many results from the fields of technology, medicine, and psychology came up without connections to MCSs. Examples of this are studies on patients with strokes or schizophrenia, studies on gait analysis, or technological investigations on cars. Motion capture is also used for investigations on animals' behavior, such as tracking the behavior of zebra fish. These articles were excluded as well. Furthermore, the search terms resulted in articles where researchers used MCSs with adults or infants as their participants.

In the first step, the titles of the articles were scanned with regard to the inclusion and exclusion criteria. For example, the following title showed that the topic of the article was not relevant for our review: "Does caffeine consumption affect laparoscopic skills in a motion tracking analysis? A prospective, randomized, blinded crossover trial" [46]. In the second step, to further decide whether the articles fit the inclusion and exclusion criteria, the abstracts of the remaining articles were read.

These two steps led to an exclusion of 2964 articles, which did not fulfill the first inclusion criterion (school education). A total of 92 articles were excluded because schoolchildren were not the participants of the study (second inclusion criterion). Furthermore, 14 articles were excluded because they focused on university/college education and 121 articles because they focused on extracurricular activities. In addition, there were 43 articles that had school students as the participants in their study, but the study itself did not investigate a subject related to school education. These articles were excluded in the same way as the 32 articles in which no MCSs were used.

In total, this means that 3372 articles were excluded (2740 based on their titles, 267 after reading the abstracts, and 365 duplicates were removed).

2.4. Analysis Step

The analysis of the 20 remaining articles was conducted in different steps. In terms of content reduction, the articles were first summarized and the main aspects relevant to this review were extracted. In the second step, the articles were scanned and coded with regard to eight main categories, which were derived deductively from the research questions. The following eight main categories were formed:

1. The types of systems and the systems used, 2. how the MCSs were used, 3. the purposes of use, 4. the aims/research questions, 5. the subjects/topics addressed, 6. the places/locations of use, 7. the potential benefits of MCSs perceived by researchers, and 8. the underlying theory of movement.

After coding all articles with regard to these main categories, the summaries of the articles were used to inductively work out the subcategories following inductive category formation [47]. Based on these subcategories, all articles were coded a second time. All coding was conducted by the first author of this paper. For example, one research question addressed the location/place of the MCSs' use. In our results, we grouped the locations where the study took place in comparable settings, such as school settings, university or laboratory settings, or outdoors. This set of groups was then used to answer the research questions.

3. Results

In this section, the results of the analysis are presented. In the first step, all 20 articles were evaluated based on the categories named in Section 2.4. These nine main categories form the following subsections. In every subsection, first, the main category is defined if needed, and, second, the findings are presented. A detailed overview of the analysis of the 20 articles can be found in Appendix A.

3.1. The Types of Systems and the Systems Used

In this main category, the MCSs were sorted into types. The types of MCSs and the concrete names of the systems that were used in the analyzed studies are shown in Figure 3.

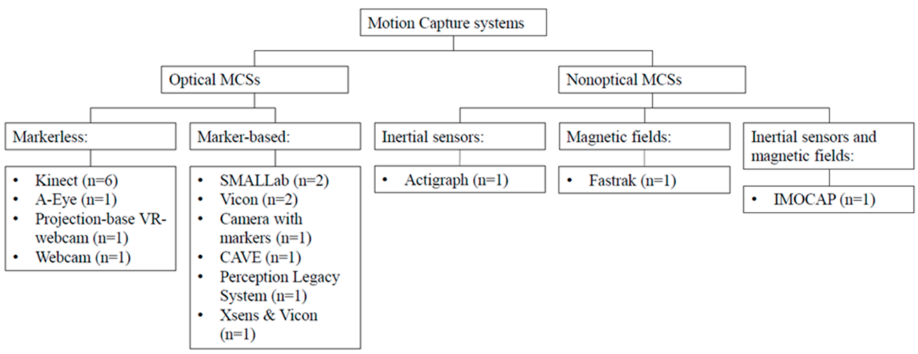

Figure 3. MCSs: overview of types and systems.

Optical as well as nonoptical systems were used by the studies in our review. Within the group of optical MCSs, the systems can be further distinguished depending on whether or not they use markers: nine studies used markerless systems [12,14,16,17,48–52] and eight studies used marker-based systems [11,15,18,53–57]. Among markerless systems, the Kinect was used in six out of nine studies.

The other type of MCS is the group of nonoptical systems. Nonoptical systems were used in three studies: One nonoptical system based on inertial sensors was used [58]. In another study, a system that uses magnetic fields was chosen [59]. One more system also belonged to the nonoptical systems. Based on the information of the authors Jaime-Gil et al. [10], this system used both inertial sensors and magnetic fields. Using both at the same time is the reason why this nonoptical system was added as a separate subcategory instead of assigning it to one or both of the other subcategories of nonoptical systems.

This main category furthermore lists the names of the MCSs used in the different studies.

Regarding the question of which systems were used concretely in the studies, we found that, in total, 13 different MCSs were used in 20 studies, which indicates a variety of MCSs used. These 13 MCSs build the subcategories here. The 20 articles differed largely in how detailed the used MCS was described. Due to this, some MCSs are listed as a separate subcategory, though they could possibly be grouped into a different subcategory if additional information were available.

Often, Kinect was used [12,16,17,48,50,51]. Originally, the Kinect device was developed by Microsoft for the Xbox360. Some articles give more detailed information about which version of the Kinect device was chosen. Depending on when the studies were conducted, different versions such as the Kinect V1 or Kinect V2 were used.

The Vicon system was used three times [18,53,54]. De Martino et al. [54] stated that they used Vicon Cara.

The system SMALLab (Situated Multimedia Arts Learning Lab) was used twice [11,55].

The following systems were used in one study each: Actigraph GT3X+ [58], A-Eye [49], a digital SLR camera (Fujifilm Finepix S6500fd) and reflective markers [56], Fastrak [59], IMOCAP [10], Perception Legacy System [15], a projection-base VR-webcam [14], CAVE (Cave Automatic Virtual Environment) [57], a webcam [52], and Xsens [53].

Grouped in the optical marker-based systems are the following MCSs: Xsens, Vicon, Perception Legacy System, CAVE, and the digital SLR camera Fujifilm Finepix S6500fd used together with reflective markers. In the optical markerless systems are the following: Kinect, A-Eye, and a webcam (used without markers).

Three systems were assigned to the group of nonoptical systems. The system based on inertial sensors is Actigraph GT3X+. Fastrak is the system included in our review that uses magnetic fields for motion capture. As mentioned in Section 4.1, one system, IMOCAP, uses both inertial sensors and magnetic fields for motion capture.

3.2. How MCSs Are Used

To have a closer look at how MCSs are used in various studies, we included this category. This category describes which body regions were recorded and evaluated using the MCSs. The recorded regions of the body were also the inductive criteria for coding the different studies. The results or which body regions were recorded in the analyzed articles are shown in Table 1.

Table 1. How MCSs are used.

MCS—Type of Use:	Frequencies:
Whole body	8
Upper extremities (arms & hands)	4
External objects (e.g., "wand")	4
Hands	1
Head	1
Facial expressions	1
Hand & fingers	1
Hip	1

The first subcategory uses MCSs for tracking the whole body. In total, the whole body was tracked in eight studies [10,12,15–17,49,50,53]. One example of this is Sempere-Tortosa et al.'s [16] investigation, where the Kinect system was used to track 25 different body joints of students with ADHD to analyze their movements.

In four studies [48,51,54,56], the researchers used the MCS to record the movements of the upper extremities. For example, Johnson-Glenberg et al. [51] tracked the spinning of the participants' arms.

Another subcategory groups all studies in which the movement of external objects is tracked. Three studies belong in this subcategory [11,52,55,57]. A prototypical example is the SMALLab systems used twice [11,55]. It uses a wand as an external object that the participants hold in their hands. This wand is tracked by the cameras.

Above, we described the subcategory upper extremities as the subcategory where the arm and hand are tracked together. Separate from it, there are two more subcategories focusing on parts of the upper extremities, hands, and hand and fingers. These subcategories have to be separated because the difference in how detailed the body regions are tracked is great. The study assigned to the subcategory hands [14] recorded the participants' hands movements in a virtual environment. The study assigned to the subcategory hand and fingers [18] tracked the position of the participants' hands in general and their index fingers in detail while reading mathematical expressions in braille language.

In one study [59], the body region of focus was the head. Bao et al. [59] tracked the head's position and declination "to compare working distance and head declination between different near-vision tasks" [59] (p. 909).

Finally, facial expressions while performing sign language [54] and the hip's movement during gardening [58] were the body regions of interest.

3.3. The Purposes of Use

This main category corresponds to the third research question. The aim is to have a closer look at educational scientists' purposes for using MCSs in their research.

Based on the 20 papers included in our systematic review, we were able to categorize the purpose of the studies into three subcategories: supporting the learning process, analysis, and programming a tutoring system. Which of these purposes was pursued and how often in the analyzed studies can be seen in Table 2.

Table 2. MCS—purpose of use.

MCS—Purpose of Use:	Frequencies:
Support the learning process	10
Analysis	7
Programming the tutoring system	3

The subcategory supporting the learning process was developed to collect all articles where the MCSs were used by the students themselves during the process of learning new content. All ten articles that described the MCS for this purpose used the system because they attributed to it particular ways of supporting the learning process [11,12,14,48,50–52,55–57]. In a typical example for this subcategory, Johnson-Glenberg et al. [11] explained in detail how in their view, MCSs support better learning outcomes. Their main reasons are that, first, using MCSs animates students to embody learning, and second, in their design, students benefited from collaborating with each other while using the MCS for learning [11]. Ip et al. [57] gave another explanation of how MCSs support the learning process. They used a marker-based optical system in a virtual learning environment. This "can provide the sense of presence to the children while keeping them away from potential danger or unnecessary embarrassment" [57] (p. 3).

The articles grouped in the subcategory analysis used MCSs as a tool for analyzing, for example, the students' behaviors or their learning gains before and after an intervention. An example of the seven studies in this subcategory [10,16–18,49,58,59] is the work performed by Sempere-Tortosa et al. [16,17], who analyzed the movements of students with ADHD using the Kinect device.

Chen et al. [15], De Martino et al. [54], and Sionti et al. [53] did not use the MCS directly in contact with the students when they learned. Instead, they used it before the concrete learning process to program a tutoring system that helps the students learn better. De Martino et al. [54], for example, used the Vicon Cara system to develop a signing avatar that translated schoolbooks into sign language for deaf and hard-of-hearing students. After tracking these movements, the researchers used the videotapes to support senior high school students in improving their dancing skills. The senior high school students themselves did not use the MCS, but they used the outcome.

3.4. The Aims of the Studies and Research Questions

Another research question, which is also in the main category, addresses the research aims of the studies using MCSs in educational research. Three central research aims were found in the 20 papers included in our systematic review: the evaluation of a developed program, the design and evaluation of a tool, and the analysis of the skills/behaviors of students. The categorized research aims and their frequencies of use are shown in Table 3.

Table 3. Aims of the studies and research questions.

Aim of the Articles/Research Questions:	Frequencies:
Evaluation of a developed program	13
Design and evaluation of a tool	4
Analysis of skills/behaviors of students	3

In 13 out of 20 studies, the aim of researchers was to evaluate a learning program that the researchers developed to educate students [10–12,14,15,48,50–53,55–57]. Semeraro et al. [50], for example, developed Relive, “a serious game focusing on increasing kids and young adults’ awareness on CPR [cardiopulmonary resuscitation]” [50] (p. 27). Their aim in using an MCS was to evaluate “if the use of Relive allows schoolchildren to improve their awareness on cardiac arrest and acquire adequate skills in CC [chest compression] that would last over time” [50] (p. 28).

The subcategory design and evaluation of a tool represents studies with the aim to develop and/or evaluate an educational tool that supports students’ learning. These tools can be tools used by the students themselves, but they can also be tools that are used to observe students and their behavior. This subcategory contains four studies [16,49,54,58]. An example of a tool that the students are supposed to use themselves is the signing avatar developed by De Martino et al. [54], described in the previous section. De Martino et al. [54] aimed to evaluate the intelligibility of their educational tool. In contrast, Myers and Wells [58] evaluated the reliability and validity of an observation tool for students’ physical activity while gardening.

The aim of the three studies classified in the third subcategory was to analyze the skills or behaviors of students [17,18,59]. For example, van Leendert et al. [18] “investigated the performances and strategies of braille readers in mathematics using finger-tracking technology” (p. 69). After this, they compared their performances and strategies with students who read printed mathematical expressions.

3.5. The Subjects/Topics Addressed

We furthermore investigated which school subjects or which topics related to school education MCSs are used for. An overview of the subjects, the topics, and how often MCSs were used for each subject/topic are listed in Table 4.

Table 4. Subjects/topics.

Subjects/Topics:	Frequencies:
special education	7
natural science (biology, chemistry, physics)	5
physical education	3
special education; mathematics	1
language	2
interdisciplinary	1
mathematics	2

We found that in addition to specific subjects, MCSs were used for topics related to special education. Seven out of twenty studies studied special education topics [12,16,17,52,54,56,57]. As previously mentioned, Sempere-Tortosa et al. [16,17] investigated the movements of students with ADHD, and De Martino et al. [54] focused on hard-of-hearing students.

Focusing on the specific subjects, natural science—including biology, physics, and chemistry—was one of the studied subjects. Five studies' focus was on natural science [11,50,51,55,58]. Johnson-Glenberg et al. [11], for example, explored the learning process of students using MCSs during chemistry—acids and bases—and biology—disease transmission—lessons.

Another subject using MCSs was physical education. Jaime-Gil et al. [10] developed a motion-capture-based gymnastics program to help students improve their body stability. Two more studies [15,60] used MCSs in physical education.

Two studies were grouped in the subcategory language. Sionti et al. [53] used a program based on motion capture to teach students the distinction between the literal and metaphorical use of motion verbs. The other study in this subcategory described the evaluation of MoviLetrando. It is an augmented reality game for learning vowels and/or consonants [14]. The program MoviLetrando can also be used to teach numbers from one to ten. Because of this, Guarnieri et al.'s study [14] was sorted into two subcategories: first into the subcategory language, and second, together with one other article [48], into the subcategory mathematics. While Guarnieri et al. [14] developed their program to teach numbers, Nathan and Swart [48] aim to improve students' skills in geometry reasoning and proofs.

The study by van Leendert et al. [18] concentrated on mathematics and special education at the same time. They analyzed the performance and strategies of visually impaired and not visually impaired students. Because the article by van Leendert et al. [18] focused on both mathematics and special education, it was categorized into a subcategory named special education and mathematics.

One more study [59] sits in a separate subcategory because the study cannot be assigned to a specific subject or to special education. In an interdisciplinary study, Bao et al. [59] analyzed the influence of near tasks, i.e., reading, writing, and playing video games, on the posture of myopic school students.

3.6. The Places/Locations of Use

In this main category, the places/locations where MCSs were used were investigated. The results are illustrated in Table 5.

The MCSs included in our review were mainly studied in two kinds of places: a laboratory or a room at the university and the school itself. Both places were each chosen nine times.

The nine studies allocated to the subcategory laboratory/(university)room used the MCS in a non-natural environment [14–16,18,53–56,59]. Bao et al. [59] chose the university or a laboratory as a setting for their study because it was possible for them to control the external factors, such as the lighting conditions.

Table 5. Places/locations of use of MCSs.

MCS—Place of Use:	Frequencies:
Laboratory/university room	9
School/classroom/gymnasium at school	9
Outside (school garden)	1
No information	1

The same number of studies were performed in schools [10–12,17,48–52]. All these studies took place in school, but different locations within the school were chosen, such as a classroom or the gymnasium of the school. Johnson-Glenberg et al. [11] installed their MCS, SMALLab, in a regular classroom. Here, they worked with the students in their natural learning environment. In contrast, Jaime-Gil et al.'s [10] research took place in the gymnasium of the school.

Separate from the subcategory school, we formed the subcategory outside, which includes one article [58]. The study took place also on the grounds of a school but in the school garden. We separated this subcategory from the before-mentioned subcategory school, as it is interesting to point out that MCSs were used both in indoor and outdoor settings.

One more article [57] could not be assigned to any of the aforementioned subcategories because there was no information given about the location where the MCS was used.

3.7. The Potential Benefits of MCSs Perceived by Researchers

This category aims to represent results about the potential benefit of the MCSs. Not all the studies provided information about the performance of the systems. However, the ones providing information can be categorized into the two subcategories of positive feedback and negative responses.

In total, the feedback about using MCSs in educational research is more positive than negative. Johnson-Glenberg et al. [11] and Luna-Oliva et al. [12], for example, concluded that MCSs are an effective tool for supporting the learning process. Furthermore, MCSs are commended as tools for providing objective information [49]. They enable detailed analysis, in the example of students' dance movements [15]. More reported feedback is that the uses of MCSs for educating students "elicit larger amounts of sensorimotor activity" [51] (p. 56). The scholars assess this as positive because they conclude "that the greater the amount of efferent motor activity, then the stronger the memory trace will be (assuming the gestures meaningfully map to the content to be learned)" [51] (p. 56). More commentary is given addressing special MCSs. PARAGON, developed and evaluated by Myers and Wells [58], aims to measure students' activity in school gardens. They describe their tool as valid and better at measuring moderate and vigorous physical activity than accelerometry [58]. Johnson-Glenberg and Hekler [55] have used the SMALLab system and suggest "great promise for using a mixed-reality environment for nutrition education" (p. 358).

There are also negative responses to MCSs. Sempere-Tortosa et al. used Kinect V2 to analyze the movements of students with ADHD. They describe Kinect as a "suitable device" [16] (p. 12) but mention its limitations as well. The Kinect system lacks occlusion in seated positions and can better detect participants in standing positions. Moreover, the Kinect is good for detecting broad movements. It is less precise with small and fine movements [16]. In the study of van Leendert et al. [18] a Vicon system was used for motion capture. For this system, the authors also described a "technical limitation [. . .] that, during finger tracking, the markers of the two index fingers were occasionally too close to distinguish one from the other" [18] (p. 79).

3.8. Underlying Theory of Movement

This category and the corresponding research question give information about how the use of MCSs is linked to a theory of movement in education. Since these systems are used for capturing movements in all studies, movement has to have a key position.

In five studies, a reference to a theory of movement can be found [11,48,51,53,55]. All of these referred to the theory of embodiment within embodied learning.

Referring to different scholars in the field of embodiment, such as Clark [61], Glenberg [62], and Varela et al. [63], Nathan and Swart [48] note, "the process of meaning making is constructed through enactment of a continuous interplay of cognitive, motoric and perceptual processes" (p. 1928). Alberto et al. [64] investigated embodied learning and stated that students can be led towards a conceptualization of the content to be learned by actively performing movements that are connected with the concept the students are supposed to learn.

In line with this, Johnson-Glenberg et al. [11], as the authors of a study analyzed in this review, note that when students had the opportunity to learn in an embodied learning environment, "they learned significantly more than students in the regular instruction condition" (p. 94).

4. Discussion

The aim of the systematic review was to provide an overview of MCSs and their use in educational research. In particular, we focused our systematic review on recent empirical studies using MCSs in research at primary, secondary and high schools. Through a database search and a systematic screening procedure, we identified 20 papers to be included in our review, which focused on school education and schoolchildren as participants. The relatively small number of included studies ($N = 20$) limits the generalizability of our findings, and in particular, it does not allow us to make solid claims about frequencies of MCSs used, etc. However, it offers valuable insights, for example, into the fact that certain systems are being used in educational research and how they are used. In the following, we will take this limitation into consideration when discussing our results.

However, there are also further limitations in this review. In addition to the strict criteria for inclusion and exclusion, the chosen search terms are a limitation. Even though they were chosen broadly, they are limited by not including the names of concrete MCSs as search terms. This limitation was necessary because it was not possible to ensure all MCSs were included, and we did not want to add additional search criteria. Research extending this review by using similar screening criteria but different identification criteria, such as other databases and languages, might extend the findings.

4.1. Discussion of the Results

The results of this review showed that based on the categorization of MCSs used for this work (see Section 1.1), optical MCSs as well as nonoptical MCSs were used. This outcome does not support that of Menolotto et al. [13], who noted that in the industry sector, nonoptical systems are most commonly used. A possible explanation might be, as Hasler states, that for optical systems, "the amount of preparation of the subject is minimal" [6] (p. 820). Similarly, Luna-Oliva et al. [12] justified their choice of using the Kinect system by describing its simple usability and motivating functionality for school children.

Secondly, it is important to highlight that there are undoubtedly different ways of using MCSs in educational research. The way of using the systems depends on the scholars' aims. Nevertheless, we found that MCSs are either used for capturing the movements of the whole body, the upper extremities, or external objects that are held in the hands. In seven studies included in our review, an MCS was used together with other equipment, such as the Resusci Anne Mannequin [50].

We found that one purpose of using MCSs in the studies included in our review was to have an objective tool to analyze students' movements. This is similar to the use of MCSs to analyze patients' gaits in medicine, e.g., [17,24–26]. Unlike studies in other scientific fields, our review study indicated that MCSs in the educational domain are also used for the purpose of directly or indirectly supporting the learning process, e.g., [11,12,54]. Either they are used during the actual learning process by the students or in advance during the development of learning programs. Interestingly, in all studies where nonoptical systems were used, the purpose of use was analysis. Therefore, it can be assumed that nonoptical systems are more often used for analysis purposes. This trend should be further investigated in future research.

We further analyzed and categorized the research aims and questions of existing MCS-based research. Our results can offer scientists an idea of which kinds of educational research MCSs are interesting tools to use. The results of the review showed that MCSs are used when the aim is to develop and/or evaluate learning programs or support tools as well as when students' skills or behaviors related to movement are the points of interest.

Another important finding is that the MCSs in the studies included in our review were used for a huge range of subjects/topics. Physical education may seem like an obvious subject to use MCSs as MCSs are an analyzing tool for movements and physical education involves movement. However, the studies in our review illustrated the usage of MCSs in natural science, mathematics, language, and special education.

Another intriguing result lies in the fact that scholars chose the school and its buildings as a location for their study as well as laboratory settings.

Regarding the theories used, it was notable that all studies that focused their research on the theory of embodiment/embodied learning pursued the research aim of evaluating a developed learning program for school students. This relationship raised the assumption that MCSs in educational research are well suited for developing and evaluating embodied learning programs. Based on the predominantly positive feedback on the MCSs described in the studies analyzed in this review, we anticipate that MCSs will be used increasingly in the future.

Apart from the 20 studies included in this systematic review, we want to mention one more article as an example for further research on MCSs in education [65]. This article was excluded because the sample did not include school children as participants. In their study, Asakawa et al. first tested a program with adults that is intended to be used with students in the future. It shows another interesting approach for using MCSs as a tool for programming a tutoring system. Asakawa et al. developed a tutoring system for visually impaired children. This system is intended to support students in learning mathematics to look at "dynamic changes in shape" [65] (p. 3619). This example illustrates once more manifold potential that the use of MCSs holds in educational research and also, in particular, for research in (mathematics) didactics.

4.2. Implications for Future Research

This review gave a structured overview of the usage of MCSs in the field of educational research. Even though the overview, which was based on 20 included studies, was not comprehensive, it showed how diverse the possibilities of using MCSs in this field are. Summarizing the results of this review may provide the first insights for researchers on what kind of educational research aims can be carried out using MCSs. In addition, the results of our review may serve as a springboard for planning more comprehensive review studies, research projects, the selection of MCSs, and the types of applications.

Our review has identified many ways in which MCSs are used and can be used. We assume that the variety of use cases of MCSs in educational research will increase in the future. In addition, we saw that previous studies using MCSs have drawn mostly positive conclusions regarding the use of the systems, which additionally is a factor that can promote the further advent of MCSs in educational research in the future—especially with systems that are relatively easy to use for nontechnicians, such as nonoptical systems. In didactic subject studies, such as in mathematics or physics education, the use of MCSs is likely to increase in the future, especially when movement plays a role in teaching, such as in science experimentation. Furthermore, the use of MCSs also offers potential in educational fields where it is not intuitive to use embodiment and motion capture. Using MCSs gives the impetus to think again about how different topics can be taught using embodied learning in subjects such as mathematics and history or in atypical learning environments such as outdoor settings. It is likely that in the future, similar to the use and recent advent of video-based eye-tracking systems in educational research [66–68], the noninvasive systems in specific optical markerless systems will be used in educational research. This will open up new opportunities for empirical findings but also for new questions and aims to be pursued. We hope that our systematic review will be useful to researchers in these future endeavors.

5. Conclusions

The number of applications of MCSs is continually increasing, just as the technology of MCSs is always evolving. While in the beginning, MCSs were used in the medical field, today they are increasingly used in many more research areas. This review indicates how MCSs can be used in the field of educational research. In the 20 papers included in our review, we saw that there was a large variety of MCSs used. These can be classified as either optical or nonoptical systems. The way MCSs were used in the studies also varied. For example, MCSs were often used to track the entire body. Our review indicates that MCSs can be used to support the learning process, for behavior analysis, and for programming tutoring systems. The aims of the articles included in our review focused on the evaluation of developed programs, the design and evaluation of tools, and the analysis of skills/behaviors. Furthermore, the MCSs were used in many different subjects and also a lot in special education contexts. The studies investigated the use of MCSs in laboratory/university settings, as well as in school settings and outdoors. Aside from a few negative comments, researchers evaluated the use of MCSs as mostly positive. Some researchers also relied their study on embodiment theoretically. Our review contributes to this body of research by structuring and expanding the use of MCSs in the field of educational research, which may give other researchers an overview of which kinds of MCSs can be used for different purposes and aims. This review has shown that MCSs were most commonly used in different subjects and locations for three different purposes: to support and capture students' movements during their learning process, for analysis, and during the process of programming a tutoring system. The findings presented in this paper can hopefully provide a springboard for further research using MCSs in educational research.

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Appendix A

Table A1. The types of systems and the systems used.

#	Title of the Paper	Type of System	System Used
1	Exploration of the effect of telerehabilitation in a school-based setting for at-risk youth [52]	Optical system (markerless)	Webcam
2	Influence of Near Tasks on Posture in Myopic Chinese Schoolchildren [59]	Nonoptical system (magnetic fields)	Fastrak

Table A1. *Cont.*

#	Title of the Paper	Type of System	System Used
3	Improve dancing skills with motion capture systems: case study of a taiwanese high school dance class [15]	Optical system (marker based)	Perception Legacy system
4	Possibilities and implications of using a motion-tracking system in physical education [49]	Optical system (markerless)	A-Eye
5	Test-Retest Reliability and Clinical Feasibility of a Motion-Controlled Game to Enhance the Literacy and Numeracy Skills of Young Individuals with Intellectual Disability [14]	Optical system (markerless)	Projection-base VR-webcam
6	Enhance emotional and social adaptation skills for children with autism spectrum disorder: A virtual reality enabled approach [57]	Optical system (marker based)	CAVE
7	Basic gymnastics program to support the improvement of body stability in adolescents [10]	Nonoptical system (inertial sensors and magnetic fields)	IMOCAP
8	Alien health game': An embodied exergame to instruct in nutrition and MyPlate [55]	Optical system (marker based)	SMALLab
9	Collaborative Embodied Learning in Mixed Reality Motion-Capture Environments: Two Science Studies [11]	Optical system (marker based)	SMALLab
10	If the gear fits, spin it! Embodied education and in- game assessments [51]	Optical system (markerless)	Kinect
11	Kinect Xbox 360 as a therapeutic modality for children with cerebral palsy in a school environment: A preliminary study [12]	Optical system (markerless)	Kinect
12	Signing avatars: making education more inclusive [54]	Optical system (marker based)	Vicon Cara
13	Quiet eye training facilitates visuomotor coordination in children with developmental coordination disorder [56]	Optical system (marker based)	Digital SLR camera with reflective markers
14	Children's physical activity while gardening: Development of a valid and reliable direct observation tool [58]	Nonoptical system (inertial sensors)	Actigraph GT3X+
15	Materialist epistemology lends design wings: educational design as an embodied process [48]	Optical system (markerless)	Kinect V2
16	Kids (learn how to) save lives in the school with the serious game Relive [50]	Optical system (markerless)	Kinect V1
17	Objective Analysis of Movement in Subjects with ADHD. Multidisciplinary Control Tool for Students in the Classroom [16]	Optical system (markerless)	Kinect V2
18	Movement Patterns in Students Diagnosed with ADHD, Objective Measurement in a Natural Learning Environment [17]	Optical system (markerless)	Kinect
19	An Embodied Tutoring System for Literal vs. Metaphorical Concepts [53]	Optical system (marker based)	Xsens and Vicon
20	An Exploratory Study of Reading Mathematical Expressions by Braille Readers [18]	Optical system (marker based)	Vicon

Table A2. How MCSs are used.

#	Title of the Paper	MCS—Type of Use
1	Exploration of the effect of telerehabilitation in a school-based setting for at-risk youth [52]	External objects (red, blue, and green gaming balls)
2	Influence of Near Tasks on Posture in Myopic Chinese Schoolchildren [59]	Head

Table A2. *Cont.*

#	Title of the Paper	MCS—Type of Use
3	Improve dancing skills with motion capture systems: case study of a taiwanese high school dance class [15]	Whole body
4	Possibilities and implications of using a motion-tracking system in physical education [49]	Whole body (multiple people's movements; no separate joints tracked)
5	Test-Retest Reliability and Clinical Feasibility of a Motion-Controlled Game to Enhance the Literacy and Numeracy Skills of Young Individuals with Intellectual Disability [14]	Hands
6	Enhance emotional and social adaptation skills for children with autism spectrum disorder: A virtual reality enabled approach [57]	External object (viewing googles)
7	Basic gymnastics program to support the improvement of body stability in adolescents [10]	Whole body (anterroposterior, mediolateral, and craniocaudal axis)
8	Alien health game': An embodied exergame to instruct in nutrition and MyPlate [55]	External object (wand)
9	Collaborative Embodied Learning in Mixed Reality Motion-Capture Environments: Two Science Studies [11]	External object (wand)
10	If the gear fits, spin it! Embodied education and in- game assessments [51]	Upper extremities
11	Kinect Xbox 360 as a therapeutic modality for children with cerebral palsy in a school environment: A preliminary study [12]	Whole body
12	Signing avatars: making education more inclusive [54]	Upper extremities (arms and hands), facial expression
13	Quiet eye training facilitates visuomotor coordination in children with developmental coordination disorder [56]	Shoulder and elbow
14	Children's physical activity while gardening: Development of a valid and reliable direct observation tool [58]	Right hip
15	Materialist epistemology lends design wings: educational design as an embodied process [48]	Upper extremities (arms and hands)
16	Kids (learn how to) save lives in the school with the serious game Relive [50]	Whole body
17	Objective Analysis of Movement in Subjects with ADHD. Multidisciplinary Control Tool for Students in the Classroom [16]	Whole body
18	Movement Patterns in Students Diagnosed with ADHD, Objective Measurement in a Natural Learning Environment [17]	Whole body
19	An Embodied Tutoring System for Literal vs. Metaphorical Concepts [53]	Whole body
20	An Exploratory Study of Reading Mathematical Expressions by Braille Readers [18]	Hand and fingers

Table A3. The purposes of use.

#	Title of the Paper	MCS—Purpose of Use:
1	Exploration of the effect of telerehabilitation in a school-based setting for at-risk youth [52]	Support the learning process
2	Influence of Near Tasks on Posture in Myopic Chinese Schoolchildren [59]	Analysis
3	Improve dancing skills with motion capture systems: case study of a taiwanese high school dance class [15]	Programming the tutoring system
4	Possibilities and implications of using a motion-tracking system in physical education [49]	Analysis
5	Test-Retest Reliability and Clinical Feasibility of a Motion-Controlled Game to Enhance the Literacy and Numeracy Skills of Young Individuals with Intellectual Disability [14]	Support the learning process

Table A3. *Cont.*

#	Title of the Paper	MCS—Purpose of Use:
6	Enhance emotional and social adaptation skills for children with autism spectrum disorder: A virtual reality enabled approach [57]	Support the learning process
7	Basic gymnastics program to support the improvement of body stability in adolescents [10]	Analysis
8	Alien health game': An embodied exergame to instruct in nutrition and MyPlate [55]	Support the learning process
9	Collaborative Embodied Learning in Mixed Reality Motion-Capture Environments: Two Science Studies [11]	Support the learning process
10	If the gear fits, spin it! Embodied education and in- game assessments [51]	Support the learning process
11	Kinect Xbox 360 as a therapeutic modality for children with cerebral palsy in a school environment: A preliminary study [12]	Support the learning process
12	Signing avatars: making education more inclusive [54]	Programming the tutoring system
13	Quiet eye training facilitates visuomotor coordination in children with developmental coordination disorder [56]	Support the learning process
14	Children's physical activity while gardening: Development of a valid and reliable direct observation tool [58]	Analysis
15	Materialist epistemology lends design wings: educational design as an embodied process [48]	Support the learning process
16	Kids (learn how to) save lives in the school with the serious game Relive [50]	Support the learning process
17	Objective Analysis of Movement in Subjects with ADHD. Multidisciplinary Control Tool for Students in the Classroom [16]	Analysis
18	Movement Patterns in Students Diagnosed with ADHD, Objective Measurement in a Natural Learning Environment [17]	Analysis
19	An Embodied Tutoring System for Literal vs. Metaphorical Concepts [53]	Programming the tutoring system
20	An Exploratory Study of Reading Mathematical Expressions by Braille Readers [18]	Analysis

Table A4. The aims of the studies and research questions.

#	Title of the Paper	Aim of the Articles/Research Questions
1	Exploration of the effect of telerehabilitation in a school-based setting for at-risk youth [52]	Evaluation of a developed program
2	Influence of Near Tasks on Posture in Myopic Chinese Schoolchildren [59]	Analysis of skills/behavior of students
3	Improve dancing skills with motion capture systems: case study of a taiwanese high school dance class [15]	Evaluation of a developed program
4	Possibilities and implications of using a motion-tracking system in physical education [49]	Possibilities and implications of using a motion-tracking system in physical education
5	Test-Retest Reliability and Clinical Feasibility of a Motion-Controlled Game to Enhance the Literacy and Numeracy Skills of Young Individuals with Intellectual Disability [14]	Evaluation of a developed program
6	Enhance emotional and social adaptation skills for children with autism spectrum disorder: A virtual reality enabled approach [57]	Evaluation of a developed program
7	Basic gymnastics program to support the improvement of body stability in adolescents [10]	Evaluation of a developed program

Table A4. *Cont.*

#	Title of the Paper	Aim of the Articles/Research Questions
8	Alien health game': An embodied exergame to instruct in nutrition and MyPlate [55]	Evaluation of a developed program
9	Collaborative Embodied Learning in Mixed Reality Motion-Capture Environments: Two Science Studies [11]	Evaluation of a developed program
10	If the gear fits, spin it! Embodied education and in- game assessments [51]	Evaluation of a developed program
11	Kinect Xbox 360 as a therapeutic modality for children with cerebral palsy in a school environment: A preliminary study [12]	Evaluation of a developed program
12	Signing avatars: making education more inclusive [54]	Design and evaluation of a tool
13	Quiet eye training facilitates visuomotor coordination in children with developmental coordination disorder [56]	Evaluation of a developed program
14	Children's physical activity while gardening: Development of a valid and reliable direct observation tool [58]	Design and evaluation of a tool
15	Materialist epistemology lends design wings: educational design as an embodied process [48]	Evaluation of a developed program
16	Kids (learn how to) save lives in the school with the serious game Relive [50]	Evaluation of a developed program
17	Objective Analysis of Movement in Subjects with ADHD. Multidisciplinary Control Tool for Students in the Classroom [16]	Design and evaluation of a tool
18	Movement Patterns in Students Diagnosed with ADHD, Objective Measurement in a Natural Learning Environment [17]	Analysis of skills/behavior of students
19	An Embodied Tutoring System for Literal vs. Metaphorical Concepts [53]	Evaluation of a developed program
20	An Exploratory Study of Reading Mathematical Expressions by Braille Readers [18]	Analysis of skills/behavior of students

Table A5. The subjects/topics addressed.

#	Title of the Paper	Subjects/Topics
1	Exploration of the effect of telerehabilitation in a school-based setting for at-risk youth [52]	Special education
2	Influence of Near Tasks on Posture in Myopic Chinese Schoolchildren [59]	Interdisciplinary
3	Improve dancing skills with motion capture systems: case study of a taiwanese high school dance class [15]	Physical education
4	Possibilities and implications of using a motion-tracking system in physical education [49]	Physical education
5	Test-Retest Reliability and Clinical Feasibility of a Motion-Controlled Game to Enhance the Literacy and Numeracy Skills of Young Individuals with Intellectual Disability [14]	Language; mathematics
6	Enhance emotional and social adaptation skills for children with autism spectrum disorder: A virtual reality enabled approach [57]	Special education
7	Basic gymnastics program to support the improvement of body stability in adolescents [10]	Physical education
8	Alien health game': An embodied exergame to instruct in nutrition and MyPlate [55]	Natural science
9	Collaborative Embodied Learning in Mixed Reality Motion-Capture Environments: Two Science Studies [11]	Natural science
10	If the gear fits, spin it! Embodied education and in- game assessments [51]	Natural science

Table A5. *Cont.*

#	Title of the Paper	Subjects/Topics
11	Kinect Xbox 360 as a therapeutic modality for children with cerebral palsy in a school environment: A preliminary study [12]	Special education
12	Signing avatars: making education more inclusive [54]	Special education
13	Quiet eye training facilitates visuomotor coordination in children with developmental coordination disorder [56]	Special education
14	Children's physical activity while gardening: Development of a valid and reliable direct observation tool [58]	Natural science
15	Materialist epistemology lends design wings: educational design as an embodied process [48]	Mathematics
16	Kids (learn how to) save lives in the school with the serious game Relive [50]	Natural science
17	Objective Analysis of Movement in Subjects with ADHD. Multidisciplinary Control Tool for Students in the Classroom [16]	Special education
18	Movement Patterns in Students Diagnosed with ADHD, Objective Measurement in a Natural Learning Environment [17]	Special education
19	An Embodied Tutoring System for Literal vs. Metaphorical Concepts [53]	Language
20	An Exploratory Study of Reading Mathematical Expressions by Braille Readers [18]	Special education; mathematics

Table A6. The places/locations of use.

#	Title of the Paper	MCS—Place of Use
1	Exploration of the effect of telerehabilitation in a school-based setting for at-risk youth [52]	School/classroom/gymnasium at school
2	Influence of Near Tasks on Posture in Myopic Chinese Schoolchildren [59]	Laboratory/university room
3	Improve dancing skills with motion capture systems: case study of a taiwanese high school dance class [15]	Laboratory/university room
4	Possibilities and implications of using a motion-tracking system in physical education [49]	School/classroom/gymnasium at school
5	Test-Retest Reliability and Clinical Feasibility of a Motion-Controlled Game to Enhance the Literacy and Numeracy Skills of Young Individuals with Intellectual Disability [14]	Laboratory/university room
6	Enhance emotional and social adaptation skills for children with autism spectrum disorder: A virtual reality enabled approach [57]	No information
7	Basic gymnastics program to support the improvement of body stability in adolescents [10]	School/classroom/gymnasium at school
8	Alien health game': An embodied exergame to instruct in nutrition and MyPlate [55]	Laboratory/university room
9	Collaborative Embodied Learning in Mixed Reality Motion-Capture Environments: Two Science Studies [11]	School/classroom/gymnasium at school
10	If the gear fits, spin it! Embodied education and in- game assessments [51]	School/classroom/gymnasium at school
11	Kinect Xbox 360 as a therapeutic modality for children with cerebral palsy in a school environment: A preliminary study [12]	School/classroom/gymnasium at school
12	Signing avatars: making education more inclusive [54]	Laboratory/university room
13	Quiet eye training facilitates visuomotor coordination in children with developmental coordination disorder [56]	Laboratory/university room

Table A6. *Cont.*

#	Title of the Paper	MCS—Place of Use
14	Children's physical activity while gardening: Development of a valid and reliable direct observation tool [58]	Outside (school garden)
15	Materialist epistemology lends design wings: educational design as an embodied process [48]	School/classroom/gymnasium at school
16	Kids (learn how to) save lives in the school with the serious game Relive [50]	School/classroom/gymnasium at school
17	Objective Analysis of Movement in Subjects with ADHD. Multidisciplinary Control Tool for Students in the Classroom [16]	Laboratory/university room
18	Movement Patterns in Students Diagnosed with ADHD, Objective Measurement in a Natural Learning Environment [17]	School/classroom/gymnasium at school
19	An Embodied Tutoring System for Literal vs. Metaphorical Concepts [53]	Laboratory/university room
20	An Exploratory Study of Reading Mathematical Expressions by Braille Readers [18]	Laboratory/university room

Table A7. The potential benefits of MCSs perceived by researchers.

#	Title of the Paper	MCS—Benefits
1	Exploration of the effect of telerehabilitation in a school-based setting for at-risk youth [52]	
2	Influence of Near Tasks on Posture in Myopic Chinese Schoolchildren [59]	
3	Improve dancing skills with motion capture systems: case study of a taiwanese high school dance class [15]	Positive feedback
4	Possibilities and implications of using a motion-tracking system in physical education [49]	Positive feedback
5	Test-Retest Reliability and Clinical Feasibility of a Motion-Controlled Game to Enhance the Literacy and Numeracy Skills of Young Individuals with Intellectual Disability [14]	
6	Enhance emotional and social adaptation skills for children with autism spectrum disorder: A virtual reality enabled approach [57]	
7	Basic gymnastics program to support the improvement of body stability in adolescents [10]	
8	Alien health game': An embodied exergame to instruct in nutrition and MyPlate [55]	Positive feedback
9	Collaborative Embodied Learning in Mixed Reality Motion-Capture Environments: Two Science Studies [11]	Positive feedback
10	If the gear fits, spin it! Embodied education and in- game assessments [51]	Positive feedback
11	Kinect Xbox 360 as a therapeutic modality for children with cerebral palsy in a school environment: A preliminary study [12]	Positive feedback
12	Signing avatars: making education more inclusive [54]	
13	Quiet eye training facilitates visuomotor coordination in children with developmental coordination disorder [56]	
14	Children's physical activity while gardening: Development of a valid and reliable direct observation tool [58]	Negative feedback
15	Materialist epistemology lends design wings: educational design as an embodied process [48]	
16	Kids (learn how to) save lives in the school with the serious game Relive [50]	
17	Objective Analysis of Movement in Subjects with ADHD. Multidisciplinary Control Tool for Students in the Classroom [16]	Positive and negative feedback
18	Movement Patterns in Students Diagnosed with ADHD, Objective Measurement in a Natural Learning Environment [17]	
19	An Embodied Tutoring System for Literal vs. Metaphorical Concepts [53]	
20	An Exploratory Study of Reading Mathematical Expressions by Braille Readers [18]	Negative feedback

Table A8. Underlying theory of movement.

#	Title of the Paper	Underlying Theory of Movement
1	Exploration of the effect of telerehabilitation in a school-based setting for at-risk youth [52]	
2	Influence of Near Tasks on Posture in Myopic Chinese Schoolchildren [59]	
3	Improve dancing skills with motion capture systems: case study of a taiwanese high school dance class [15]	
4	Possibilities and implications of using a motion-tracking system in physical education [49]	
5	Test-Retest Reliability and Clinical Feasibility of a Motion-Controlled Game to Enhance the Literacy and Numeracy Skills of Young Individuals with Intellectual Disability [14]	
6	Enhance emotional and social adaptation skills for children with autism spectrum disorder: A virtual reality enabled approach [57]	
7	Basic gymnastics program to support the improvement of body stability in adolescents [10]	
8	Alien health game': An embodied exergame to instruct in nutrition and MyPlate [55]	Embodiment
9	Collaborative Embodied Learning in Mixed Reality Motion-Capture Environments: Two Science Studies [11]	Embodiment
10	If the gear fits, spin it! Embodied education and in- game assessments [51]	Embodiment
11	Kinect Xbox 360 as a therapeutic modality for children with cerebral palsy in a school environment: A preliminary study [12]	
12	Signing avatars: making education more inclusive [54]	
13	Quiet eye training facilitates visuomotor coordination in children with developmental coordination disorder [56]	
14	Children's physical activity while gardening: Development of a valid and reliable direct observation tool [58]	
15	Materialist epistemology lends design wings: educational design as an embodied process [48]	Embodiment
16	Kids (learn how to) save lives in the school with the serious game Relive [50]	
17	Objective Analysis of Movement in Subjects with ADHD. Multidisciplinary Control Tool for Students in the Classroom [16]	
18	Movement Patterns in Students Diagnosed with ADHD, Objective Measurement in a Natural Learning Environment [17]	
19	An Embodied Tutoring System for Literal vs. Metaphorical Concepts [53]	Embodiment
20	An Exploratory Study of Reading Mathematical Expressions by Braille Readers [18]	

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