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# EMBODIED LEARNING IN A DIGITAL WORLD: A SYSTEMATIC REVIEW OF EMPIRICAL RESEARCH IN K-12 EDUCATION

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Abstract: There is a wide-spread assumption that technology enhanced learning environments, which are grounded on the notion of embodied cognition, can promote learning. The current study reviews the empirical basis of this assumption by examining literature published from 2008 to 2017 which employs embodied learning environments in K-12 education. As part of this study, we review a total of 41 empirical studies and we focus on the type of embodied learning environments utilized, the research methods adopted for their evaluation and the educational contexts in which they are implemented. At the core of this review study, we investigate students' learning gains whilst examining the learning effectiveness of embodied learning environments, as compared to other interfaces and instructional approaches. In general, the review revealed positive outcomes from the use of embodied learning environments in K-12. Most of the reviewed studies were contextualized in K-12 STEM education, adopted gesture-based technologies and evaluated students' learning using retrospective measures grounded on pre-post questionnaires. Cognitive learning outcomes were dominant in the reviewed studies, while the evaluation of affective and psychomotor outcomes received less attention. The majority of the reviewed comparative studies reported that students in the embodied learning condition had increased learning gains, when compared to their counterparts in the control group. However, these findings should be treated with caution due to a set of methodological concerns that this review identified. We conclude this chapter with a synthesis of our findings in the form of emerged implications and we provide a set of guidelines for future research and practice in the field of embodied learning environments.

Key words: Embodied cognition, Technology-enhanced learning, Embodied learning environments, Learning outcomes, K-12 education

# 1. INTRODUCTION

Embodied learning appears to have gained ground during the last decade, seeking for the ways in which embodied cognition theory may be enacted and applied in the field of education. Embodied learning, as an application area of embodied cognition theory, constitutes a contemporary pedagogy of learning, which emphasizes the use of the body in the educational practice (Anderson, 2003; Wilson, 2002). As Nguyen and Larson (2015) explain: “Learners are simultaneously sensorimotor bodies, reflective minds, and social beings. Embodied learning provides a way through which alternative forms of teaching and learning can be integrated and accepted into the classroom” (p. 342). As such, it is not surprising that during the last decade there was a rapid development of educational technologies, which enable embodied learning practices in education.

The widespread population of affordable motion-based technologies and natural user interfaces (e.g., Wii, Xbox Kinect, Leap Motion) in combination with the emergence of immersive interfaces based on mixed or virtual reality, have opened the doors for the design of embodied learning environments, grounded on the notions of motion, physicality and interactivity (Enyedy, Danish, & DeLiema, 2015). In its essence, embodied learning environments compose an emergent category of digital environments, which integrate gestures or even full-body movement into the act of learning (Johnson-Glenberg, Savio-Ramos, & Henry, 2014; Ibánez & Wang, 2015).

Johnson-Glenberg, Birchfield, Tolentino, and Koziupa (2014) have suggested that a more rigorous understanding of embodied learning environments is needed; they proposed a taxonomy of four levels with current examples of educational technologies. According to the two lowest levels of the taxonomy, embodiment is very limited to non-existed, given that the gestural congruency is not a defining construct in the lesson, neither there is a contribution of movement to the reification of the educational content. These lowest levels of the taxonomy include desktop-based simulations or videos that are often passively viewed in smaller displays (e.g., desktops or handheld devices), thus providing no opportunities for sensorimotor engagement and immersion. In contrast, in the two upper levels of the taxonomy, embodiment is observed in higher degrees. At these upper levels, the gestural congruency is a defining aspect of the educational experience, as the embodied learning environments are equipped with motion tracking systems (e.g., Wii, Xbox Kinect, or Leap Motion); as such, hand gestures or body movements are closely mapped to the educational content which must be learned. These learning environments typically include large screen displays, floor projections, 360° head-mounted displays (HMD), virtual reality or mixed reality rooms, which are perceived as highly immersive. A more recent taxonomy provided by Skulmowski and Rey (2018), further supports that such learning environments enable high bodily engagement and embodiment integration in the learning task, given that they allow a high coupling between movement and the educational content to be learned. The present review is concerned with these highest levels of the taxonomy; lower levels of embodiment are not in the scope of this work.

As argued by Maliverni and Pares (2014), embodied learning environments open up new possibilities due to their affordances to promote psychomotor learning experiences, while also involving users with their cognitive and affective aspects. At the same time, due to their novelty and wide-ranging areas of applicability, embodied learning environments are highly intriguing to researchers, instructional designers, technology specialists and educators; however, their integration in mainstream education is at very slow pace (Abrahamson & Sánchez-García, 2016). At the same time, the evidence of the potential effectiveness of embodied learning activities is still sparse and fragmented (Maliverni & Pares, 2014), whilst many psychologists and learning scientists are concerned that such activities are nothing more than “bells and whistles”, which may falsely be perceived as educational (Goldinger, Papesh, Barnhart, Hansen, & Hout, 2016). It thus appears to be an urgent need to synthesize existing empirical research on the topic, for drawing some evidence-based conclusions about the effectiveness of embodied learning environments.

Pares and Maliverni (2014) reviewed 31 studies focusing on full-body interaction learning environments, published from 2003-2013. However, as they have reported, their review did not result in some conclusive findings about the educational value of embodied learning environments. This may be attributed to the fact that their review was mostly based on conference papers (26 out of the 31 studies), typically providing shorter debriefs of the conducted research. At the same time, embodied learning environments allowing interactions via gestures and hand movements were out of scope in the review of Pares and Maliverni (2014). In another study, Sheu and Chen (2014), reviewed 59 studies for investigating the trends of gesture-based computing research in education, published from 2001-2013. However, Sheu and Chen (2014) investigated how the gesture-based technologies were applied pedagogically aiming at identifying pedagogical differences between the learning domains; the authors did not investigate the impact of the embodied environments on students' learning. In addition, as their review focused particularly on gesture-based technologies, full-body interaction learning environments were out of scope.

The present review study examines the empirical research, which has been published during the last decade, between the years 2008-2017 and is concerned with students' learning gains due to their participation at embodied learning environments. As such, our effort addresses the need for collecting and synthesizing empirical evidence regarding the learning effectiveness of this emerging type of educational environments; this need has not yet been addressed sufficiently by prior review efforts. In addition, rather than focusing on a subset of embodied learning environments (e.g., gesture-based or full-body), the present review sets as a unifying axis the notion of embodied cognition for capturing all of the empirical studies related to the topic. More specifically, the present study examines the empirical studies on embodied learning environments in K-12 education, with the goal of investigating the following five research questions:

(1) What types of embodied learning environments *(type of embodied technologies, duration of embodied learning interventions)* are utilized in K-12 education?
(2) What are the educational contexts *(learning disciplines, number and age of students*) in which embodied learning environments are used?
(3) What research methods *(research designs and assessment techniques)* are used for evaluating students' learning gains during the implementations of embodied learning environments?
(4) What kinds of learning gains are evident as students participate in embodied learning environments?
(5) Do students learn more through their participation in embodied learning environments, as compared to other instructional methods and interfaces?

# 2. METHOD

## 2.1 Data collection

The studies analyzed in this literature review covered empirical research published from 2008 to 2017. The published literature was surveyed using four electronic databases: Education Research Complete [via EBSCO], ERIC, JSTOR, and Scopus, which are considered among the most enriched and popular academic databases. The retrieving keywords were classified in two groups (Group 1: Approach type, Group 2: Interaction type), in order to retrieve as many relevant articles as possible (Table 1). For surveying the published research in the selected databases, we searched the abstracts of the indexed studies by combining each keyword with the following terms: "Students", "Learners", "Learning gains", "Learning outcomes", "Classroom" and "School"; this ensured that the retrieval results would be mostly restricted in K-12 educational settings.

Table 1 Retrieval Keywords per Group

| **Group name** | **Search term / Phrases** |
|---|---|
| Approach type | "Embodied cognition"; "Embodied learning"; "Embodied pedagogy"; "Embodied education"; "Embodied play" |
| Interaction type | "Embodied interaction"; "Full-body interaction"; "Whole-body interaction"; "Bodily interaction"; "Gesture-based interaction"; "Touchless interaction"; "Motion-based interaction" |

After performing all possible combinations, we retrieved 306 unique studies within the field of interest, namely technology-enhanced environments for embodied learning in K-12 education. This corpus of studies was subsequently filtered according to five selection criteria. In particular, to be included in the corpus of the reviewed studies a study ought to have met all five criteria: (1) Source type: The study should have been published in English as a full paper in an academic journal; (2) Research methods: The study should be empirical, providing primary or secondary data derived from quantitative, qualitative, or mixed designs; (3) Type of intervention: The study should report on the investigation of a technology-enhanced environment for embodied learning (included in the upper levels of the embodied taxonomy, as suggested by Johnson-Glenberg et al., 2014); (4) Research focus: The study should be related to the research focus of the present review, i.e. reporting on students' learning gains, (5) Participants: The study participants should be K–12 students.

After applying these selection criteria 24 eligible peer-reviewed, journal articles remained in the review corpus. In addition, a complementary search in Google Scholar, and using the same selection criteria, led to the retrieval of 10 more empirical studies. This initial corpus was enriched by using the "ancestry" method (Cooper, 1982), according to which we searched the references of the identified research articles for empirical studies that could be included in the present review. This process yielded 7 additional articles.

Overall, a total of 41 studies met all the inclusion criteria and were selected for this review; these articles are marked with an asterisk in the reference section.

## 2.2 Coding and analysis

To answer the first three research questions, focused on (a) the types of embodied learning environments (RQ1), (b) the educational contexts in which these were implemented (RQ2), and (c) the research methods adopted for evaluating the implementations (RQ3), we conducted a content analysis in the reviewed studies, without having any predetermined categories in mind.

To answer RQ4, we coded the students' learning gains reported in the studies using a coding scheme grounded on Bloom's taxonomy (1956), as a well-accepted classification scheme for categorizing learning outcomes. Traditionally, researchers have focused on the cognitive dimension of learning outcomes (e.g., Bloom, 1956; Gagné, 1977). However, the original taxonomy has been extended to include affective learning outcomes (e.g., Krathwohl, Bloom & Massai, 1964; Krathwohl et al., 2002) and psychomotor learning outcomes (e.g., Harrow, 1972; Simpson, 1966). In the present work, learning outcomes were categorized along the cognitive, affective and psychomotor learning domains.

Table 2 presents the coding scheme employed for the classification of the learning outcomes.

Table 2 Classification of the Learning Outcomes

| **Domain** | **Definition** | **Learning outcomes** |
|---|---|---|
| Cognitive | Relates to the intellectual aspects of learning | • Information searching skills<br>• Knowledge acquisition and conceptual understanding<br>• Cognitive skills (e.g., visual and auditory memory, attention, focus)<br>• Problem solving skills (e.g., analysing, synthesizing, summarizing, inferring)<br>• Metacognition skills (e.g., self-regulation, self-assessment) |

| | | |
|---|---|---|
| Affective | Relates to the emotional aspects of learning | • Motivational outcomes (e.g., interest and curiosity, willingness to learn)<br>• Engagement (e.g., immersion, sense of presence/flow, active participation)<br>• Social behaviors (e.g., social interactions, collaboration)<br>• Attitudes and dispositions |
| Psychomotor | Relates to the physical aspects of learning | • Physical skills (e.g., movement, strength, balance, speed, control, coordination, agility) |

Finally, to answer RQ5, we focused on the empirical studies examining the learning effectiveness of embodied learning environments compared to other instructional methods or interfaces. These studies were categorized according to the reported learning effectiveness in three categories: (a) Positive effect (increased learning gains in the embodied learning condition), (b) Negative effect (increased learning gains in the comparison or control group) and (c) No difference (equal learning gains in both conditions).

# 3. FINDINGS

## 3.1 Overview of the reviewed empirical studies

A total of 41 empirical studies were identified, published from 2008 to 2017, reporting on the impact of embodied learning environments for K-12 students. A total of five studies were published between 2008 and 2010 (12.2%), another eight studies were published 2011-2013 (19.5%), while twenty-eight studies were published 2014-2017 (68.3%). A considerable peak in the published studies can be observed during the period of 2014-2017, indicating the increasing interest on the topic. Most of the reviewed studies (75.6%) were published in educational-technology related journals, while the most prominent journals were *"Computers & Education"*, *"International Journal of Child-Computer Interaction"* and *"Computer Supported Collaborative Learning"*. What follows below is the presentation of the main findings per research question.

## 3.2 Type of embodied learning environments (RQ1)

According to our analysis, the majority of the reviewed studies included embodied learning environments grounded on gesture-based technologies (n=30 studies, 73.2%), as opposed to full-bodied interactive learning environments (n=11 studies, 26.8%). According to the reviewed corpus of studies, most of the full-bodied environments were grounded on mixed reality settings, where students collaborated and interacted in multi-modal learning environments using full body movements (e.g., Birchfield & Johnson-Glenberg, 2010; Lindgren, Tscholl, Wang, & Johnson, 2016). On the other hand, most of the gesture-based learning environments adopted the Microsoft Xbox Kinect technology (e.g., Altanis, Boloudakis, Retalis, & Nikou, 2013; Anderson & Wall, 2016; Hung, Lin, Fang, & Chen, 2014). Table 3 presents the distribution of the different types of embodied technologies employed in the reviewed studies.

Table 3 Distribution of Reviewed Studies per Embodied Technologies

| Type | Technologies | N (%) |
|---|---|---|
| Gesture-based environments | • Microsoft Kinect | 19 studies (46.4%) |
| | • Nintendo Wii | 5 studies (12.2%) |
| | • Web-based camera | 3 studies (7.3%) |
| | • Other | 3 studies (7.3%) |
| | | **30 studies (73.2%)** |
| Full-body environments | • Mixed reality technologies | 9 studies (21.9%) |
| | | 2 studies (4.9%) |
| | • Interactive floor | **11 (26.8%)** |

Taking into account their duration, the embodied learning environments included in the reviewed studies were classified as of short-term and long-term duration. Those of short-term duration ranged from a few minutes (e.g., Homer et al., 2014) to 70 minutes (e.g., Abrahamson, 2014). Those of long-term duration were composed by a set of at least 2 sessions (e.g., Tolentino, Birchfield, Megowan-Romanowicz, Johnson-Glenberg, Kelliher, & Martinez, 2009) up to 26 sessions (e.g., Enyedy, Danish, Delacruz, & Kumar, 2012). According to our analysis, half of the reviewed studies included embodied learning environments of short-term duration (n=20 studies, 48.8%), while n=16 studies included embodied learning environments of long-term duration (39%), or did not provide specific information on this aspect (n=5 studies, 12.2%).

## 3.3 Educational contexts (RQ2)

The educational contexts in which embodied learning environments were used, varied substantially in terms of their learning disciplines as well as in the number and age of the students involved. As shown in Table 4, the majority of studies were in the domain of STEM education (27 studies, 65.9%), followed by special education (5 studies, 12.2%) and language education (4 studies, 9.7%). The majority of the STEM-oriented reviewed studies were focused on mathematics (e.g., Abrahamson. 2014; Smith, King, & Hoyte, 2014), physics (e.g., Hung et al., 2014), geology (e.g., Birchfield & Johnson-Glenberg, 2010) and biology (e.g., Andrade, Danish, & Maltese, 2017). Finally, the rest of the studies (5 studies, 12.2%) were related to other domains such as physical education, environmental education, literacy and music.

Table 4 Distribution of Reviewed Studies per Domain/Discipline and Target Student Ages

| **Domain/Discipline** | **Target student ages** | **N (%)** |
|---|---|---|
| STEM education<br>• Mathematics (9)<br>• Physics (5)<br>• Biology (4)<br>• Geology (4)<br>• Chemistry (3)<br>• Multiple science topics (2) | K-12 education<br>• Pre-/Primary school (13)<br>• Middle school (7)<br>• High school (7) | 27 studies (65.9%) |
| Special education | K-6 education<br>• Pre-/Primary school (5) | 5 studies (12.2%) |
| Language education | K-6 & High school education<br>• Pre-/Primary school (3)<br>• High school (1) | 4 studies (9.7%) |
| Other<br>• Physical education (2)<br>• Environmental education (1)<br>• Literacy (1)<br>• Music (1) | K-6 & High school education<br>• Pre-/Primary school (4)<br>• High school (1) | 5 studies (12.2%) |

The reviewed studies in the domain of STEM education, covered the whole spectrum of K-12 system (namely Pre-/Primary school, Middle school, High school). On the other hand, the reviewed studies in special education covered only K-6 education, while the rest of the reviewed studies, related to language education and other domains, were mostly contextualized in K-6 settings rather in secondary education (Middle and High schools).

Finally, the number of participants also varied significantly, ranging from two students (Altanis et al., 2013), to one-hundred and fifty students (Jagodziński & Wolski, 2010). It is not surprising that the studies which focused on the investigation of the learning process, involved considerably fewer students (e.g., Altanis et al., 2013; Anderson & Wall, 2016; Enyedy, Danish, & DeLiema, 2015) and took the form of pilots or case studies, as compared to quantitative or mixed design studies focusing on the investigation of students' learning gains (e.g., Hsiao & Chen, 2016; Jong, Hong, &Yen, 2013; Lindgren et al., 2016).

## 3.4 Research methods (RQ3)

The empirical studies included in the present review were classified in three main categories as of: (1) Experimental research, (2) Design-based research and (3) Other types of research (see also Sheu and Chen, 2014). According to the reviewed studies' reported methods, the most of the studies (17 studies, 41.5%) adopted an experimental research design, followed by design-based research (13 studies, 31.7%) and other types of research (11 studies, 26.8%). Table 5 presents an overview of the distribution of the reviewed studies per research design.

Table 5 Distribution of Reviewed Studies per Research Design

| Research Type | Research design | N (%) |
|---|---|---|
| Experimental research | • Quasi-experimental design | 11 studies (26.8%) |
| | • Experimental design | 4 studies (9.8%) |
| | • Counterbalanced design | 2 studies (4.9%) |
| | | **17 studies (41.5%)** |
| Design-based research | • Multiple case studies | 10 studies (24.4%) |
| | • Mixed methods | 3 studies (7.3%) |
| | | **13 studies (31.7%)** |
| Other types of research | • Pilot/Evaluation studies | 5 studies (12.2%) |
| | • Case studies | 3 studies (7.3%) |
| | • Exploratory studies | 2 studies (4.9%) |
| | • Feasibility studies | 1 study (2.4%) |
| | | **11 studies (26.8%)** |

The majority of the experimental research studies were grounded on the quasi-experimental designs and employed pre-post research methods without including a control group, or included a non-equivalent pretest-posttest control group (e.g., Chiu, DeJaegher, & Chao, 2015; Hsiao & Chen, 2016). Most of the design-based research studies (n=10 studies, 24.4%) were grounded on a series of case studies, representing in most of the cases a set of multiple iterations and evaluations of a given embodied learning environment (e.g., Anderson & Wall, 2016; Malinverni Schaper,

& Pares, 2016). Finally, when focusing on the miscellaneous types of research, most of the studies had the form of pilots for evaluating the impact of embodied learning environments on students' learning (e.g., Altanis et al., 2013; Mandanici, Roda, & Canazza, 2016).

In terms of the assessment, the most common measurement were pre-post questionnaires for evaluating students' learning outcomes (30 studies, 73.2%), followed by interviews with the students (17 studies, 41.5%) and observations via field notes and annotations, or video-/audio-recordings of the learning sessions (16 studies, 39%). Assessment methods grounded on students' log files and subsequent learning analytics were identified in 9 studies (21.9%), while other evaluation methods grounded on students' artifacts, students' and teachers' comments or teacher reports were noted only in 3 studies (7.3%). It is also worth mentioning, that a total of 13 studies (31.7%) were grounded exclusively on retrospective and subjective measurements for the evaluation of embodied learning, using pre-post questionnaires (e.g., Birchfield & Johnson-Glenberg, 2010; Jagodziński & Wolski, 2014; Kuo, Hsu, Fang, & Chen, 2014).

## 3.5 Learning gains (RQ4)

All reviewed empirical studies reported that embodied learning environments can have a positive impact on at least one of the Bloom's taxonomy strands: (a) Cognitive learning outcomes, (b) Affective learning outcomes, and (c) Psychomotor learning outcomes. A study would be classified according to all types of the learning outcomes reported (e.g., a study reporting two types of learning outcomes would be classified two times, one time for each respective learning outcome). Table 6 provides an overview for the distribution of the learning outcomes reported in the reviewed studies.

Table 6 Distribution of Reviewed Studies per Research Design

| **Domain** | **Learning outcomes** | **N (%)** |
|---|---|---|
| Cognitive | • Information searching skills | ---- |
| | • Knowledge acquisition / conceptual understanding | 35 studies (85.4%) |
| | • Cognitive skills (e.g., visual and auditory memory, attention, focus) | 2 studies (4.9%) |
| | • Problem solving skills (e.g., analysing, synthesizing, summarizing, inferring) | ---- |
| | • Metacognition skills (e.g., self-regulation, self- | |

| | | |
|---|---|---|
| | assessment) | ---- |
| Affective | • Motivational outcomes (e.g., interest and curiosity, willingness to learn) | 6 studies (14.6%) |
| | • Engagement (e.g., immersion, sense of presence/flow, active participation) | 10 studies (24.4%) |
| | • Social behaviors (e.g., positive social interactions, collaboration) | 2 studies (4.9%) |
| | • Attitudes and dispositions | 1 study (2.4%) |
| Psychomotor | • Physical skills (e.g., movement, strength, balance, speed, control, coordination, agility) | 5 studies (12.2%) |

Cognitive learning outcomes were the dominant outcomes across the majority of the reviewed studies (35 studies, 85.4%), especially those contextualized in STEM education. These studies reported an increase in students' knowledge acquisition on a variety of topics related to mathematics (e.g., Smith et al., 2014), biology (e.g., Andrade et al., 2017), chemistry (e.g., Tolentino et al., 2009) or physics (e.g., Enyedy, Danish, Delacruz & Melissa, 2012). Some of the reviewed studies also reported that students were engaged with effective inquiry learning processes in the embodied learning environments employed (Tolentino et al., 2009) or that the embodied learning technologies were adopted for augmenting the inquiry-based learning process (Anderson & Wall, 2016). However, none of the reviewed studies reported on cognitive learning outcomes related to students' information searching skills, problem-solving or metacognition skills (e.g., self-regulation), which are often achieved in inquiry-based learning settings. Finally, only two of the reviewed studies (4.9%) reported on cognitive learning outcomes related to short-term memory and visual processing (Kourakli et al., 2017) or to students' spatial rotation skills (Tolentino et al., 2009).

Next, a total of 15 studies (36.6%) reported on students' affective learning outcomes. In particular, most of the reviewed studies reported on students' engagement with the learning process (e.g., Ibánez & Wang, 2015; Lindgren et al., 2016; Tolentino et al., 2009) as well as on students' increase of motivation for participation in the task (e.g., Hwang, Shih, Yeh, Chou, Ma, & Sommool, 2014; Yang et al., 2012). Only a limited number of studies reported on the contribution of embodied learning to students' attitudes and dispositions (e.g., Lindgren et al., 2016) or students' social behaviours, such as positive social interactions and collaboration (e.g., Mora-Guiard, Crowell, Pares, & Heaton, 2017; Malinverni, Mora-Guiard, Padillo, Valero, Hervás, & Pares. 2017).

Finally, only a total of five studies (12.2%) reported data on psychomotor learning outcomes. These studies were contextualized in the field of special or physical education. These studies reported on the contribution of embodied learning to students' physical skills, such as movement, strength, balance, speed, object control, coordination and agility (Altanis et al., 2013; Hsiao & Chen, 2016; Kourakli et al., 2017; Li et al., 2012; Vernadakis et al., 2015).

## 3.6 Comparison studies (RQ5)

This review indicates that 15 studies have examined the learning potential of embodied learning environments, as compared to other interfaces (3 studies, 7.3%) or forms of instructional methods (12 studies, 29.3%). Despite the diversity in their research design (e.g., type of embodied learning environments, educational context, assessment) these comparison studies investigated whether there is a significant difference in students' learning outcomes between the experimental group (grounded on embodied learning instruction/interface) and a control or comparison group.

According to the results of the reviewed studies, there were only two studies (4.9%) which reported results in favor of the comparison group. For instance, in the study of Jong, Hong, and Yen (2013), the results indicated that kindergarten children, who used a touch-based interface for learning mathematics, outperformed their counterparts in the embodied condition who used a gestured-based interface. Likewise, Anderson and Wall (2016) reported that, in contrast to a traditional hands-on inquiry activity, middle school students exhibited lack of engagement and collaboration during an inquiry-based activity structured around a Kinect-based intervention for learning physics. According to their observations, Anderson and Wall (2016) found that the students in the experimental condition were disengaged with the learning aspect of the inquiry as they perceived their interactions with Kinect as a gaming rather than as a learning experience.

In contrast, the rest of the 13 reviewed studies (86.7%) reported that students in the embodied learning condition had increased learning gains, compared to students in the control or comparison group. For instance, three of the studies reported that the embodied learning approach could result in better retention when compared to the traditional instructional approach (Kuo, Hsu, Fang, & Chen, 2014; Vernadakis et al., 2015). Two other studies indicated that students in the experimental group had increased learning gains when compared to their counterparts in the comparison group who used non-embodied interfaces, such as desktop-based computers with a keyboard and a mouse (Hung et al., 2014; Lindgren et al., 2016). Moreover, a set of studies on the evaluation of

SMALlab, as a full-body collaborative learning environment, adopted a counterbalanced research design and demonstrated that whenever students were in the SMALLab condition, they learned significantly more than their counterparts in the regular instruction condition.

# 4. DISCUSSION, IMPLICATIONS AND FUTURE STUDIES

There is a wide-spread assumption that embodied learning environments, which are grounded on physicality, motion and interactivity, open up new possibilities in the field of education and can promote student learning. The current study reviewed the empirical basis of this assumption by examining 41 empirical studies employing embodied learning environments in K-12 education, published in relevant journals during the last decade (2008-2017). As part of this review study, we focused on the type of embodied learning environments utilized, the research methods adopted for their evaluation and the educational contexts in which they were implemented. In its core, the present review has examined the findings of published empirical studies for embodied learning environments as they related to: (a) students' learning gains and (b) the learning potential of embodied learning environments, as compared to other instructional approaches and interfaces. In general, the review revealed positive outcomes from the use of embodied learning environments in K-12. In the next lines, our findings are synthesised and discussed the form of emerged implications, providing a set of guidelines for future research and practice in the field of embodied learning.

## 4.1 Design 'open' and freely-available applications for embodied learning technologies

First, our analysis has indicated that the majority of the reviewed studies included embodied learning environments grounded on gesture-based technologies, rather than full-bodied interactive learning environments. In particular, most of the embodied learning environments were based on the use of Kinect cameras. According to Sheu and Chen (2014), this finding could be attributed to the affordability of gesture-based technologies as well as how these technologies can be easily set up and used by educators in typical classroom settings, assuming relevant software is available. While full-bodied learning environments such as SMALLab (e.g., Birchfield, & Johnson-Glenberg, 2010, Johnson-Glenberg, Birchfield, & Sibel, 2009; Tolentino et al., 2009) are based on extensive hardware installations in dedicated rooms (i.e., labs), the newer generation of gesture-based technologies has made embodied learning pedagogy in the typical classroom. Indeed, gesture-based technologies (e.g., Wii, Kinect, Leap-motion) continue to become commercially available whilst being portable, robust, and affordable. In terms of software, we are facing an explosion of efforts to design gesture-based technologies and develop applications for such technologies, especially in the areas of STEM (e.g., Dahn, Enyedy, & Danish, 2018; Walkington, Chelule, Woods, & Nathan, 2018). Yet, for a wide adoption of embodied learning in education, future work could focus on the design of ‘open’ and freely-available applications for portable and affordable gesture-based technologies, which school teachers could easily link to units of the everyday curriculum.

## 4.2 Conduct more technology integration research

Based on this review, a large number of embodied learning environments were employed in the context of out-of-school activities or in laboratory settings for experimental purposes (e.g., Homer et al., 2014; Lindgren et al., 2016). Fewer embodied learning environments, mostly in studies of long-term duration, were integrated in the educational curricula, taking the form of an alternative teaching approach (e.g., Anderson & Wall, 2016; Birchfield & Johnson-Glenberg, 2010). In order for this field to grow and become a more mainstream one, future studies should be more oriented in the later, i.e., the integration and evaluation of embodied learning environments in authentic school settings, taking into account the school curricula, both content- and time-wise. Design based research seems to be the pathway to design, enact, and evaluate such technology and pedagogy innovations in authentic classrooms. Indeed, approximately one third of the reviewed studies (31.7%) adopted a design-based research approach, as they focused on the design and evaluation of embodied learning environments; yet more work is needed to address issues of technology integration including opportunities but also difficulties (e.g., classroom orchestration, technological setup, learning design) surrounding embodied learning.

## 4.3 Extend embodied learning research beyond STEM

Focusing on the educational contexts in which embodied learning environments were adopted, the majority of studies were in the domain of STEM education and covered the whole spectrum in K-12 system (namely Pre-/primary school, Middle school, High School). The prevalence of embodied learning environments in STEM education could be attributed to the fact that, while STEM-related knowledge and skills can be difficult to acquire, “fundamental STEM knowledge is itself shaped by the embodied nature of the human mind” (Abrahamson & Lindgren, 2014). While future studies should continue focusing on the integration and evaluation of embodied learning environments in STEM education, efforts should also expand to other educational domains and disciplines. For instance, embodied learning appears to have value in the domain of special and inclusive education (Kosmas, Ioannou & Retalis, 2018; Sheu & Chen, 2014). In particular, the review study of Sheu and Chen (2014), which was also expanded in adult populations, has indicated that gesture-based technologies could have a pivotal role in supporting learners with both physical and cognitive difficulties to conquer daily life skills or specific job tasks and engage in physical rehabilitation and other behavior skills training. As such, Sheu and Chen have concluded that gesture-based technologies, and mainly Wii, have significant implications in special education for disabled individuals and those with special needs. In this spirit, embodied learning might enable the creation of inclusive learning environments providing equal learning opportunities and tools for both mainstream and special education students.

## 4.4 In-situ measurements

Despite these efforts, the assessment techniques employed in the reviewed articles were characterized by the frequent use of self-reported questionnaires, which requires reflection in relation to the theoretical groundings of embodied cognition. For instance, a total of 13 studies (31.7%) evaluated embodied learning grounded exclusively on retrospective and subjective measurements, using pre-post questionnaires (e.g., Birchfield & Johnson-Glenberg, 2010; Jagodziński & Wolski, 2014; Kuo, Hsu, Fang, & Chen, 2014). This finding is also aligned with the previous review of Maliverni and Pares (2013) who argued that such a retrospective assessment is contradictory with the very nature of embodied learning, given that it fails to capture the situated construction of meaning and the bodily-based knowledge, as this is produced in-situ. Instead, such retrospective assessment techniques adopt a subjective and post-interventional measurement of the embodied phenomenon based on a stimulus–response model of learning (Kozma, 1994), which has been already deemed as inadequate for evaluating the media effects. Taking into account these findings, future studies should take into consideration the use of in-situ measurements, such as log files capturing students’ movements, video- and audio-recording capturing student’ utterance and gestural actions, as well as task-based interviews providing useful insights on how the embodied learning process is unfolded. Such efforts could also result in an evidence-based development of a coding framework, providing a set of indicators for capturing and analyzing the embodied learning phenomenon. On the other hand, rather that retrospectively measuring learning and indirectly attributing students' learning gains on the embodied experience, future research could invest on the development and validation of psychometric instruments for capturing the embodied phenomenon i.e., the embodied degree of the learning experience.

## 4.5 Beyond conceptual understanding

All of the studies included in this review investigated students' learning outcomes and indicated positive findings, in terms of promoting students' cognitive, affective and psychomotor learning gains. However, when taking into account the Bloom's taxonomy (1956), our analyses indicated lack of sufficient evidence in support of all learning strands. Instead, most of the reviewed studies examined students' cognitive learning outcomes, in terms of conceptual understanding in the context of STEM education. This finding could be attributed to several reasons. For instance, despite the curriculum reform efforts observed during the last decades, students' preparation for high-stakes testing forces an emphasis on conceptual understanding rather than on promoting other types of learning outcomes (Falk & Drayton, 2004). Another plausible explanation could be current assessment practices which, similarly, emphasize conceptual understanding (NRC, 2011) and fail to assess other aspects of learning. Our findings indicate a need for further investigation of the potential of embodied environment to facilitate students' learning beyond conceptual understanding, taking into account potential learning outcomes in the affective and psychomotor domains. Besides, as argued by Li and Tsai (2013), in order to explore the advantages of an innovative learning approach over other instruction methods, student outcomes should be compared extensively for all of the learning strands.

## 4.6 Address methodological concerns in experimental designs

A significant corpus of the empirical studies was grounded on experimental research, adopting a pre-post research design in order to gather empirical evidence for supporting the learning effectiveness of embodied learning environments. These experiments compared or contrasted the potential of embodied learning environments as compared to other forms of instruction methods and interfaces. In particular, we have identified fifteen empirical studies, with the thirteen of them (86.7%) reporting that students in the embodied learning condition had increased learning gains, when compared to students participating in the control group. However, these promising results in favour of embodied learning should be treated with caution, taking into account at least two main methodological concerns related to their: (a) sampling and (b) research design.

First, in many of the reviewer studies, the number of participants was relatively small. Therefore, as reported by some researchers, (a) the statistical power was not always sufficient for the analyses conducted (Johnson-Glenberg, Birchfield, Megowan-Romanowicz, & Snow, 2015), (b) the samples were not sufficient to verify and generalize the positive findings identified (Hwang et al., 2014), and (c) there was not enough statistical power to investigate aptitude by treatment interactions, taking for instance into account the role of students' prior knowledge (Johnson-Glenberg et al., 2014; Johnson-Glenberg et al., 2015). Future, experimental studies should make use of larger samples, which would allow the generazability of the findings as well as the investigation of aptitude by treatment interactions (McLeod, Cronbach, & Snow, 1978), taking into consideration a set of additional students' characteristics (e.g., digital skills, attitudes towards computers).

Second, in many studies, the experimental studies took place in complex educational settings, which made it difficult to identify the driving forces behind the observed learning gains. Researchers in a set of comparison studies investigating the learning effectiveness of the SMALLab, have reported that they could not define if their positive findings could be attributed to the embodied approach, to student collaboration, to the technological affordances, to the experienced novelty effect, or even to the interaction of all these factors. Future studies should therefore be grounded on research designs that allow more firm explanations on the learning effectiveness of embodied learning environments. Future studies for instance, could compare the learning impact of gesture-based learning environments with full-bodied ones; researchers could retain collaboration, embodied technologies and novelty in both conditions and isolate the impact of embodiment, given that full-body learning environments are considered as more embodied. On a different vein, future studies could compare the effectiveness of digital and not-digital embodied learning environments (see Tran, Smith Buschkuehl, 2017, for a relevant discussion). In this case, researchers, could retain embodiment, collaboration and novelty in both conditions and isolate the digital aspect for investigating the impact of digital embodied technologies. If such experimental work provides evidence in favor of embodied learning, then technology-enhanced environments for embodied learning could be the future of education.

## 5. LIMITATIONS

The papers included in the present review study were limited to journal articles indexed in the four databases (Education Research Complete [via EBSCO], ERIC, JSTOR, and Scopus) as well as in Google Scholar, or were identified via the ancestry method, and were published from 2008 to 2017. Future reviews could extent this review and include conference papers retrieved from relevant databases (e.g., ACM, IEEE). Despite the relatively limited number of studies included in this review study, we have followed a well-designed sampling process, grounded on a set of carefully selected criteria, in order to result in a systematic and coherent review study. Finally, future review studies could also be expanded on the use of embodied learning environments in higher education, by adult populations, and in other domains (e.g., medical training, physical therapy, sports and exercise science).

## 6. CONCLUSIONS

To sum up, research on technology-enhanced environments for embodied learning is a nascent but growing research area. This review has examined the literature on K-12 empirical research employing embodied learning environments. In general, the review revealed positive outcomes from the use of embodied learning environments in K-12. Analyses indicated that embodied learning seems to primarily promote cognitive learning outcomes in STEM education. Future research should be expanded in other types of learning outcomes (e.g., affective and psychomotor ones). Also, future research should be based on more objective and in-situ measurements, rather than in subjective and retrospective measurements, which are incongruent with the epistemological grounds of embodied cognition. At the same time, research should investigate the effectiveness of the embodied learning environments, as compared to other educational approaches and interfaces, using larger samples to allow for firm statistical analyses and generalizable conclusions. Finally, future studies should be grounded on research designs that enable empirical substantiation on the positive contribution of embodied learning environments, by controlling the effects of other variables such as student collaboration.

## REFERENCES

**Articles in the review corpus*

*Abrahamson, D., Lee, R. G., Negrete, A. G., & Gutiérrez, J. F. (2014). Coordinating visualizations of polysemous action: Values added for grounding proportion. *ZDM - International Journal on Mathematics Education*, *46*(1), 79–93. https://doi.org/10.1007/s11858-013-0521-7

*Abrahamson, D., & Trninic, D. (2015). Bringing forth mathematical concepts: signifying sensorimotor enactment in fields of promoted action. *ZDM Mathematics Education*, *47*(2), 295–306. https://doi.org/10.1007/s11858-014-0620-0

*Abrahamson, D. (2013). Building educational activities for understanding: An elaboration on the embodied-design framework and its epistemic grounds. *International Journal of Child-Computer Interaction*, *2*(1), 1–16. https://doi.org/10.1016/j.ijcci.2014.07.002

Abrahamson, D., & Lindgren, R. (2014). Embodiment and embodied design. In *The Cambridge Handbook of the Learning Sciences, Second Edition* (pp. 358–376). https://doi.org/10.1017/CBO9781139519526.022

*Abrahamson, D., & Sánchez-García, R. (2016). Learning Is Moving in New Ways: The Ecological Dynamics of Mathematics Education. *Journal of the Learning Sciences*, *25*(2), 203–239. https://doi.org/10.1080/10508406.2016.1143370

*Abrahamson, D., Trninic, D., Gutiérrez, J. F., Huth, J., & Lee, R. G. (2011). Hooks and shifts: A dialectical study of mediated discovery. *Technology, Knowledge and Learning*, *16 1*, 55–85. https://doi.org/10.1007/s10758-011-9177-y

*Altanis, G., Boloudakis, M., Retalis, S., & Nikou, N. (2013). Children with Motor Impairments Play a Kinect Learning Game: First Findings from a Pilot Case in an Authentic Classroom Environment. *Interaction Design and Architecture(s) Journal - IxD&A*, *19*(19), 91–104.

*Anderson, J. L., & Wall, S. D. (2016). Kinecting Physics: Conceptualization of Motion Through Visualization and Embodiment. *Journal of Science Education and Technology*, *25*(2), 161–173. https://doi.org/10.1007/s10956-015-9582-4

Anderson, M. L. (2003). Embodied Cognition: A field guide. *Artificial Intelligence*, *149*(1), 91–130. https://doi.org/10.1016/S0004-3702(03)00054-7

*Andrade, A., Danish, J., & Maltest, A. (2017). A Measurement Model of Gestures in an Embodied Learning Environment: Accounting for Temporal Dependencies. *Journal of Learning Analytics*, *4*(3), 18–45. https://doi.org/10.18608/jla.2017.43.3

*Birchfield, D., & Megowan-Romanowicz, C. (2009). Earth Science Learning in smallab: A design experiment for mixed reality. *International Journal of Computer-Supported Collaborative Learning*, *4*(4), 403–421. https://doi.org/10.1007/s11412-009-9074-8

*Birchfield, D., & Johnson-Glenberg, M. (2010). A Next Gen Interface for Embodied Learning. *International Journal of Gaming and Computer-Mediated Simulations*, *2*(1), 49–58. https://doi.org/10.4018/jgcms.2010010105

*Birchfield, D., Thornburg, H., Megowan-Romanowicz, M. C., Hatton, S., Mechtley, B., Dolgov, I., & Burleson, W. (2008). Embodiment, Multimodality, and

Composition: Convergent Themes across HCI and Education for Mixed-Reality Learning Environments. *Advances in Human-Computer Interaction*, *2008*, 1–19. https://doi.org/10.1155/2008/874563

Bloom, B. (1956). *Taxonomy of Educational Objectives – The Cognitive Domain*. New York: Donald McKay.

*Chiu, J. L., Dejaegher, C. J., & Chao, J. (2015). The effects of augmented virtual science laboratories on middle school students' understanding of gas properties. *Computers and Education*, *85*, 59–73. https://doi.org/10.1016/j.compedu.2015.02.007

Cooper, H. M. (1982). Scientific Guidelines for Conducting Integrative Research Reviews. *Review of Educational Research*, *52*(2), 291–302. https://doi.org/10.3102/00346543052002291

Dahn, M., Enyedy, N., & Danish, J. (2018). How Teachers Use Instructional Improvisation to Organize Science Discourse and Learning in a Mixed Reality Environment (pp. 72–79). London, UK: International Society of the Learning Sciences (ISLS).

*Di Tore, S., Aiello, P., Palumbo, C., Vastola, R., Raiola, G., D'Elia, F., … Sibilio, M. (2012). Sensory Motor Interaction in Virtual Environment To Promote Teaching-Learning Process. *Problems of Education in the 21st Century*, *42*, 29–37. Retrieved from http://www.proxy.its.virginia.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=ehh&AN=77924507&site=ehost-live

*Enyedy, N., Danish, J. A., & DeLiema, D. (2015). Constructing liminal blends in a collaborative augmented-reality learning environment. *International Journal of Computer-Supported Collaborative Learning*, *10*(1), 7–34. https://doi.org/10.1007/s11412-015-9207-1

*Enyedy, N., Danish, J. A., Delacruz, G., & Kumar, M. (2012). Learning physics through play in an augmented reality environment. *International Journal of Computer-Supported Collaborative Learning*, *7*(3), 347–378. https://doi.org/10.1007/s11412-012-9150-3

Falk, J., & Drayton, B. (2004). State Testing and Inquiry-Based Science: Are They Complementary or Competing Reforms? *Journal of Educational Change*, *5*(4), 345–387. https://doi.org/10.1007/s10833-004-1069-7

Gagne, R. (1970). *The Conditions of Learning*. New York: Holt, Rinehart & Winston.

Goldinger, S. D., Papesh, M. H., Barnhart, A. S., Hansen, W. A., & Hout, M. C. (2016). The poverty of embodied cognition. *Psychonomic Bulletin and Review*, *23*(4), 959–978. https://doi.org/10.3758/s13423-015-0860-1

Harrow, A. (1972). *A Taxonomy of The Psychomotor Domain: A Guide for Developing Behavior*. *New york*. New York: David McKay Co. https://doi.org/10.2307/1161665

*Homer, B. D., Kinzer, C. K., Plass, J. L., Letourneau, S. M., Hoffman, D., Bromley, M., … Kornak, Y. (2014). Moved to learn: The effects of interactivity in a Kinect-based literacy game for beginning readers. *Computers and Education*, *74*, 37–49. https://doi.org/10.1016/j.compedu.2014.01.007

*Hsiao, H. S., & Chen, J. C. (2016). Using a gesture interactive game-based learning approach to improve preschool children's learning performance and motor skills. *Computers and Education*, *95*, 151–162. https://doi.org/10.1016/j.compedu.2016.01.005

*Hung, I. C., Lin, L. I., Fang, W. C., & Chen, N. S. (2014). Learning with the body: An embodiment-based learning strategy enhances performance of comprehending fundamental optics. *Interacting with Computers*, *26*(4), 360–371. https://doi.org/10.1093/iwc/iwu011

*Hwang, W. Y., Shih, T. K., Yeh, S. C., Chou, K. C., Ma, Z. H., & Sommool, W. (2014). Recognition-based physical response to facilitate EFL learning. *Educational Technology and Society*, *17*(4), 432–445.

*Ibánez, J. de J. L. G., & Wang, A. I. (2015). Learning Recycling from Playing a Kinect Game. *International Journal of Game-Based Learning*, *5*(3), 25–44. https://doi.org/10.4018/IJGBL.2015070103

*Jagodziński, P., & Wolski, R. wola@amu. edu. p. (2014). The Examination of the Impact on Students' Use of Gestures While Working in a Virtual Chemical Laboratory for Their Cognitive Abilities. *Problems of Education in the 21st Century*, *61*, 46–57.

*Johnson-Glenberg MC, Hekler, E. (2013). An embodied, motion-capture exer-game teaching nutrition and MyPlate. *Games for Health Journal*, *2*, 354–361.

*Johnson-Glenberg, M. C., Birchfield, D. A., Tolentino, L., & Koziupa, T. (2014). Collaborative embodied learning in mixed reality motion-capture environments: Two science studies. *Journal of Educational Psychology*, *106*(1), 86–104. https://doi.org/10.1037/a0034008

*Johnson-Glenberg, M. C., Birchfield, D. A., Megowan-Romanowicz, C., & Snow, E. L. (2015). If the Gear Fits, Spin It! *International Journal of Gaming and Computer-Mediated Simulations*, *7*(4), 40–65. https://doi.org/10.4018/IJGCMS.2015100103

*Johnson-Glenberg, M. C., Birchfield, D., & Usyal, S. (2009). *SMALLab* : virtual geology studies using embodied learning with motion, sound, and graphics. *Educational Media International*, *46*(4), 267–280. https://doi.org/10.1080/09523980903387555

*Johnson-Glenberg, M. C., Savio-Ramos, C., & Henry, H. (2014). "Alien Health": A Nutrition Instruction Exergame Using the Kinect Sensor. *Games for Health Journal*, *3*(4), 241–251. https://doi.org/10.1089/g4h.2013.0094

*Jong, J. T., Hong, J. C., & Yen, C. Y. (2013). Persistence temperament associated with children playing math games between touch panel and embodied interaction. *Journal of Computer Assisted Learning*, *29*(6), 569–578. https://doi.org/10.1111/jcal.12017

Kosmas, P., Ioannou, A., & Retalis, S. (2018). Moving bodies to moving minds: A study of the use of motion-based games in special education. *TechTrends*, 1–8. https://doi.org/10.1007/s11528-018-0294-5

*Kourakli, M., Altanis, I., Retalis, S., Boloudakis, M., Zbainos, D., & Antonopoulou, K. (2017). Towards the improvement of the cognitive, motoric and academic skills of students with special educational needs using Kinect learning games. *International Journal of Child-Computer Interaction*, *11*, 28–39. https://doi.org/10.1016/j.ijcci.2016.10.009

Kozma, R. B. (1994). Will media influence learning? Reframing the debate. *Educational Technology Research and Development*, *42*(2), 7–19. https://doi.org/10.1007/BF02299087

Krathwohl, D. R., Bloom, B. S., Massai, B. B. (1964). *Taxonomy of educational objectives: The classification of educational goals*. White Plains, NY: Longman.

Krathwohl, D. R., Anderson, L. W., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., … Wittrock, M. C. (2002). *A Taxonomy For Learning, Teaching, And Assessing: A Revision Of Bloom's Taxonomy Of Educational Objectives*. *New York Longman*. New York, NY: Addison Wesley Longman. https://doi.org/10.1207/s15430421tip4104_2

*Kuo, F. R., Hsu, C. C., Fang, W. C., & Chen, N. S. (2014). The effects of Embodiment-based TPR approach on student English vocabulary learning achievement, retention and acceptance. *Journal of King Saud University - Computer and Information Sciences*, *26*(1), 63–70. https://doi.org/10.1016/j.jksuci.2013.10.003

*Li, K., Lou, S., Tsai, H., & Shih, R. (2012). The effects of applying game-based learning to webcam motion sensor games for autistic student's sensory integration. *Tojet*, *11*(4), 451–459. Retrieved from http://www.tojet.net/articles/v11i4/11446.pdf

Li, M.-C., & Tsai, C.-C. (2013). Game-Based Learning in Science Education: A Review of Relevant Research. *Journal of Science Education and Technology*, *22*(6), 877–898. https://doi.org/10.1007/s10956-013-9436-x

*Lindgren, R., Tscholl, M., Wang, S., & Johnson, E. (2016). Enhancing learning and engagement through embodied interaction within a mixed reality simulation. *Computers and Education*, *95*, 174–187. https://doi.org/10.1016/j.compedu.2016.01.001

*Malinverni, L., Mora-Guiard, J., Padillo, V., Valero, L., Hervás, A., & Pares, N. (2017). An inclusive design approach for developing video games for children with Autism Spectrum Disorder. *Computers in Human Behavior*, *71*, 535–549. https://doi.org/10.1016/j.chb.2016.01.018

Malinverni, L., & Pares, N. (2014). Learning of Abstract Concepts through Full-Body Interaction: A Systematic Review. *Educational Technology & Society*, *17*(4), 100–116. https://doi.org/10.2307/jeductechsoci.17.4.100

*Malinverni, L., Schaper, M. M., & Pares, N. (2016). An evaluation-driven design approach to develop learning environments based on full-body interaction. *Educational Technology Research and Development*, *64*(6), 1337–1360. https://doi.org/10.1007/s11423-016-9468-z

*Mandanici, M., Roda, A., & Canazza, S. (2016). The Harmonic Walk: An Interactive Physical Environment to Learn Tonal Melody Accompaniment. *Advances in Multimedia*, *2016*. https://doi.org/10.1155/2016/4027164

McLeod, D. B., Cronbach, L. J., & Snow, R. E. (1978). *Aptitudes and Instructional Methods: A Handbook for Research on Interactions*. *Journal for Research in Mathematics Education* (Vol. 9). New York: Irvington. https://doi.org/10.2307/748778

*Mora-Guiard, J., Crowell, C., Pares, N., & Heaton, P. (2017). Sparking social initiation behaviors in children with Autism through full-body Interaction. *International Journal of Child-Computer Interaction*, *11*, 62–71. https://doi.org/10.1016/j.ijcci.2016.10.006

Nguyen, D. J., & Larson, J. B. (2015). Don't Forget About the Body: Exploring the Curricular Possibilities of Embodied Pedagogy. *Innovative Higher Education*, *40*(4), 331–344. https://doi.org/10.1007/s10755-015-9319-6

NRC (2011). *Learning science through computer games and simulations*. (H. M., Honey M. A., Ed.), *Studies in Science Education*. Washington, DC: The National Academies Press.

Sheu, F. R., & Chen, N. S. (2014). Taking a signal: A review of gesture-based computing research in education. *Computers and Education*, *78*, 268–277. https://doi.org/10.1016/j.compedu.2014.06.008

*Si, M. (2015). A virtual space for children to meet and practice chinese. *International Journal of Artificial Intelligence in Education*, *25*(2), 271–290. https://doi.org/10.1007/s40593-014-0035-7

Simpson, E. J. (1972). *The Classification of Educational Objectives in the Psychomotor Domain*. *Education* (Vol. 3). Urbana, IL: University of Illinois. Retrieved from http://eric.ed.gov/ERICWebPortal/recordDetail?accno=ED010368

Skulmowski, A., & Rey, G. D. (2018). Embodied learning: introducing a taxonomy based on bodily engagement and task integration. *Cognitive Research: Principles and Implications*, *3*(1), 6. https://doi.org/10.1186/s41235-018-0092-9

*Smith, C., King, B., & Gonzalez, D. (2016). Using multimodal learning analytics to identify patterns of interactions in a body-based mathematics activity. *Journal of Interactive Learning Research*, *27*(4), 355–379.

*Smith, C. P., King, B., & Hoyte, J. (2014). Learning angles through movement: Critical actions for developing understanding in an embodied activity. *Journal of Mathematical Behavior*, *36*, 95–108. https://doi.org/10.1016/j.jmathb.2014.09.001

*Tolentino, L., Birchfield, D., Megowan-Romanowicz, C., Johnson-Glenberg, M. C., Kelliher, A., & Martinez, C. (2009). Teaching and learning in the mixed-reality science classroom. *Journal of Science Education and Technology*, *18*(6), 501–517. https://doi.org/10.1007/s10956-009-9166-2

Tran, C., Smith, B., & Buschkuehl, M. (2017). Support of mathematical thinking through embodied cognition: Nondigital and digital approaches. *Cognitive Research: Principles and Implications*, *2*(1), 16. https://doi.org/10.1186/s41235-017-0053-8

*Vernadakis, N., Papastergiou, M., Zetou, E., & Antoniou, P. (2015). The impact of an exergame-based intervention on children's fundamental motor skills. *Computers and Education*, *83*, 90–102. https://doi.org/10.1016/j.compedu.2015.01.001

Walkington, C., Chelule, G., Woods, D., & Nathan, M. J. (2018). Collaborative Gesture as a Case of Distributed Mathematical Cognition Gesture as Simulation Action Research questions (pp. 552–559). London, UK: International Society of the Learning Sciences (ISLS).

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin and Review*, *9*(4), 625–636. https://doi.org/10.3758/BF03196322

*Yang, J. C., Chen, C. H., & Chang Jeng, M. (2010). Integrating video-capture virtual reality technology into a physically interactive learning environment for English learning. *Computers and Education*, *55*(3), 1346–1356. https://doi.org/10.1016/j.compedu.2010.06.005

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