Intellectual Output 1-Task 2

An overview of embodied cognition and kinesthetic learning applied to support SEN children

CONSORTIUM

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Executive Summary

INTELed project aims at providing teachers with knowledge and skills about the use of interactive ICT multi-sensory techniques oriented to SEN children with a focus on inclusive education. The first step towards that aim is to define a pedagogical framework for SEN education driven by theories of embodied cognition and kinesthetic learning, which is the focus of O1.

This report presents an overview of the theoretical framework of embodiment, and of the associated concepts of embodied cognition, embodied interaction and embodied learning.

The theories of embodiment are gaining momentum due to the appearance of innovative (and affordable) interactive technologies that enable new forms of interaction between humans and computers. This report presents a taxonomy of these technologies and identifies motion-based body-gesture interfaces as the most appropriate for the purposes of INTELed. The characteristics of these interfaces fit well with the needs of children with motor impairments, Autistic Syndrome Disorder, Attention Deficit Hyperactivity Disorder (ADHD), and other mental disabilities. However, the specificity of each person with disability makes it difficult to generalize. Therefore, the tools offered to these persons need to provide a high level of personalization, and the degree of effectiveness of their application depends on the particular condition of the person.

This report reviews the studies that have applied the aforementioned interaction technologies to special education children, and reports on the evidence provided by these studies. Initial evidence shows positive results on different aspects related to learning, such as motivation, attention, emotional and social benefits, etc. However, in spite of this positive evidence, the methodology and scope of the reviewed studies does not allow for generalizable results. There is also a need of further research in the area to gain insight into the mechanisms that make these applications effective for improving the conditions of children with different types of disabilities, and in general, to know to what extent embodied cognition theories can be applied to these children.

The report identifies lines of further research, such as the need to study the application of these technologies to children in inclusive classroom settings.

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1. Introduction

INTELed aims at providing teachers with knowledge and skills about the use of interactive ICT multi-sensory techniques oriented to SEN children with a focus on inclusive education. The first step towards this aim is to define a pedagogical framework for SEN education driven by theories of embodied cognition and kinesthetic learning, which is the focus of O1.

To inform this pedagogical framework, it is necessary to provide an overview of embodied cognition and kinesthesic learning technologies applied to children with SEN, which is the focus of this report.

Embodied cognition is an approach with roots in many disciplines and that has led to different types of applications. For this reason, the first goal of this review is to provide a description of the theoretical framework that will help understand the main concepts involved in the project, such as embodied learning and embodied interaction.

Embodied interaction can be supported by a number of technologies, which may comprise from gesture-based interaction in tablets to virtual reality environments. There is a need to specify which technologies are more suited for their application with children with SEN. This aspect will be covered in this report.

Finally, it is necessary to know which is the current evidence on the benefits of the chosen technologies applied to children with SEN for the improvement of which aspect of learning, as well as the design principles derived from the existing studies that can be applied to the usage of embodied interaction technologies to SEN children.

This report addresses all the aforementioned issues. First, it provides an overview of the main concepts related to embodiment and its conceptual background. Then, the report describes the technologies that will be considered in the project as the base of the embodied learning experiences. Finally, we report on the collected evidence on the usage of these technologies for learning (in general), and for learning applied to SEN children.

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2. Theoretical Framing

2.1. Embodied Cognition and Embodiment

Embodied Cognition (EC), henceforth EC, has now been proved to be a significant part of contemporary theories of cognitive sciences. The fascinating insight of EC is that behaviour is not simply the output of someone's isolated brain (Anderson, 2003), but that cognitive processes are deeply rooted in the body's interactions with the world (Wilson, 2002). Consequently, in this theory, the body plays a central role in shaping the mind; from this perspective, the mind is not only connected to the body, but the body influences the mind. As Atkinson (2010) stated "we experience, understand, and act on the world through our bodies" (p. 599). Lakoff (2012) explains the EC as cognition depending on the body with all its sensorimotor capacities and characteristics and its experiences in a way that the body is inseparably connected to the mind. In doing so, humans' cognition is influenced by their experiences in the physical world.

In the literature, there are many definitions of EC in different disciplines and fields. The common idea about the theory of EC is that the body plays a significant role in shaping the mind. Wilson (2002), trying to determine the general thesis of EC gives the following definition:

> *"Many features of cognition are embodied in that they are deeply dependent upon characteristics of the physical body of an agent, such that the agent's beyond-the-brain body plays a significant causal role, or a physically constitutive role, in that agent's cognitive processing"* (Wilson, 2002).

Under the umbrella of EC, theories of embodiment have been presented within the cognitive science (Farr, Price, & Jewitt, 2012). Embodiment theory, like EC theory, views the body inseparable from the mind and emphasizes the role of external environment in cognitive processes. Dreyfus (1996) in discussing the work of Merleau-Ponty, pointed out three different meanings of embodiment. The first is the physical embodiment of a human subject; the second is the set of bodily skills and situational responses that we have developed; and the third is the cultural abilities and understandings that we responsively gain from the cultural world in which we are embedded. Situated cognition is a theory that seems to have a direct relationship with EC theory. "Situated" appears as a synonym of "embodied" in a few studies. As Wilson (2002) says, "Situated cognition is cognition that takes place in the context of task-relevant inputs and outputs and involves interaction with the things that the cognitive activity is about" (p. 626). Although it is obvious that EC and situated cognition are complementary and closely related, the relation between embodied and situated theory, yet is not clear or well-defined.

The EC theory has a relatively short history in the academic research and it has only been studied empirically in the last decades. Since 1990 talking about embodiment has become increasingly frequent in philosophy (Clark, 2008), psychology (Aizawa, 2015); (Chandler & Tricot, 2015), neuroscience (Kiefer & Trumpp, 2012), education (Chao, Huang, Fang, & Chen, 2013; Chang, Chien, Chiang, Lin, & Lai, 2013), linguistics and language learning (Kuo, Hsu, Fang, & Chen, 2014; Lakoff, 2012; Lan, Chen, Li, & Grant, 2015) and in dynamical systems approaches to behavior and thought (Spencer, Perone, & Johnson, 2008). The beginnings of EC are in the 1980s, when the idea of the

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mind as embodied and situated emerged; related work was conducted in philosophy (Dreyfus, 1996), biology (Varela, Thompson, & Rosch, 2016), cognitive psychology (Barsalou, 2008), and cognitive linguistics (Lakoff & Johnson, 2008) among others. Lakoff and Johnson (2008) in their work titled "Metaphors we live by" suggested that our way of reasoning and thinking is derived from our bodily actions. Our understanding is shaped by our experience on the particular physical form of our bodies and their everyday interaction with the real world. In this view, cognition then is influenced, if not determined, by humans' experiences with the world (Atkinson, 2010; Barsalou, 2008; Glenberg, Witt, & Metcalfe, 2013; Kiefer & Trumpp, 2012; Wilson, 2002). Moreover, an emerging viewpoint is that the mind must be understood only through its relationship to the bodily interactions in the world. In order to explain the term of EC in a more meaningful way Wilson (2002) made six claims:

- Cognition is Situated (cognition takes place in the context where the interactivity with the things related to cognitive activity happen).
- Cognition is Time Pressured (how cognition functions under the pressures of real time interaction with the environment).
- We off-load cognitive work onto the environment (because of limits on our information-processing abilities).
- The environment is part of the cognitive system.
- Cognition is for action (the mind's function is to guide action in the way that behaviour and environment are interdependent).
- Off-line cognition is body based (this is the most important aspect of EC, as all physical activity feeds into on-line cognition at some level).

During the last decades, the embodied view has accepted a lot of criticism from the theorists of cognitive science. Unlike the fundamental (cognitive) theories about the development of human cognition, EC gives attention to the dynamic interplay between bodily shapes and experiences with the whole brain system and their interaction in real-life context and environment (Aizawa, 2015). As Anderson (2003) mentioned, criticism is that EC cannot be true because the physically disabled are obviously able to learn, communicate and acquire concepts; everyone is able to understand and comprehend things, which they have not experienced at all, through imagination, demonstration, and testimony. In that way, the physically disabled are in this regard no different from other people (Anderson, 2003). Cognitive scientists claim that the brain is the only producer of cognition and completely ignore the role of the environment and the dependence of mind on the body (Wilson, 2002). Contrary to this view of cognition, the EC theory argues that cognition can occur as a continuous interaction between a mind, a body and a world. According to the theory of EC, the body and mind are dependent of each other.

2.2. Embodied Interaction

EC theory became prominent issue around the field of Human Computer Interaction (HCI) with the work of (Dourish, 2001) who suggested the term "embodied interaction". As (Dourish, 2001) points out, *"Embodiment is the property of our engagement with the world that allows us to make it meaningful*" and thus "*Embodied Interaction is the creation, manipulation, and changing of meaning through engaged interaction with artifacts*" (p.3). Thus, research in the HCI area aims to explore

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appropriate design methodologies and strategies for developing interactive experiences in service of learning, with essential considerations for how we can design for the interactions between people, objects, and spaces (Dourish, 2004).

Trends in interaction and "embodiment" is the basis for a new foundational approach to HCI. Indeed, recent developments in the HCI field have moved their attention to the role of immersive and multisensory interaction using multimodal and multitasking interface design. Designing for embodiment requires focus on bodily movements and interaction with different specific physical or virtual things. Embodiment involves new forms of interaction such as the use of multi-sensor artifacts, gesture technologies, or whole-body interaction (Farr et al. 2012). Dourish (2001) states the need of creating new ways of interacting with digital reality, which can better satisfy the people's needs and abilities. Overall, HCI plays an important role in the implementation of these new kinds of interactivity based on the EC theory.

2.3. Embodied Learning

Embodied Learning (EL) appears to have gained ground during the last decade, seeking for the ways in which EC theory may be enacted in the field of education. As Nguyen and Larson (2015) explain: *"Learners are simultaneously sensorimotor bodies, reflective minds, and social beings. EL provides a way through which alternative forms of teaching and learning can be integrated and accepted into the classroom"* (p. 342). Embodied learning practice, as a part of EC, constitutes a contemporary pedagogical theory of learning which emphasizes the use of the body in the educational practice (Anderson, 2003; Wilson, 2002).

Embodied education has been defined as the basic concept which includes embodied teaching and embodied learning (Lindgren & Johnson-Glenberg, 2013). Johnson-Glenberg, Birchfield, Tolentino, and Koziupa (2014) argue that "*the more modalities (sensorimotor systems) are activated during the encoding of the information, then the crisper and more stable the representations will be in schematic storage. These crisper representations, with more modal associative overlap, will be more easily recalled*" (p. 130). The term "body" in the embodied learning approach includes the physical body, the senses, the mind, and the brain, that is, the whole of the student's personality. According to Lindgren and Johnson-Glenberg (2013) the primary principles of embodied learning are the following:

- the sensorimotor activity,
- the relevance of gestures to the theme that is to be reproduced, and
- the emotional involvement of the participant in the whole process.

Without a doubt, education is a research area in which the theory of embodied cognition has strong implications (Leitan & Chaffey, 2014). However, there is limited empirical research that studies the use of embodied technologies in real classrooms settings.

In the literature some studies and papers refer to kinesthetic learning, as a synonym of embodied learning. Kinesthetic is the learning environment in which the learner physically interacts with the learning experience. The word "kinesthesia", proposed by Merleau-Ponty, is the movement sense and in that way the body is the perceiver and human's perception involves both sensory and motor processes. According to Ayala, Mendívil, Salinas, and Rios (2013) kinesthetic learning offers new experiences in education, giving the learner the opportunity to take action in the learning process. In other words, kinesthetic perception and sensorimotor experiences are tools to facilitate learning.

3. A taxonomy of embodied technologies

There is a number of related and overlapping terms and definitions for technologies that support embodied interaction, including Mixed Reality Environments (MREs) (Rogers, Scaife, Gabrielli, Smith, & Harris, 2002), Full-body Interaction Learning Environments (FUBILEs) (Malinverni & Pares, 2014), Exer-learning games (Lucht & Heidig, 2013), Natural User Interfaces (Evans & Rick, 2014), Blended Learning Environments (Kirkley & Kirkley, 2002), Digitally Augmented Physical Spaces (Price & Rogers, 2004) and Tangible User Interfaces (TUIs) (Ishii & Ullmer, 1997). As important as it might be, this report shall not focus on the fine nuances and differences between such concepts. Instead, we adopt the most acceptable term of "Tangible User Interfaces" (TUIs).

The term “Tangible User Interface” was coined and introduced by Ishii and Ullmer (1997) as an extension of the idea of the “grasp and manipulate” interface to make computing truly invisible and ubiquitous (Evans & Rick, 2014). A tangible user interface is an interface in which a user interacts with a digital system through the manipulation of a physical object, including his own body, augmenting the physical world by coupling digital information and everyday physical objects and environments. TUIs enable different kinds of engagement with the body and allow learners explore the world more concretely. They host innovative forms of interaction, based on gestures, body movements or physical manipulation of real objects, and support a greater emphasis on the role of the physical body and environment in embodied interaction (Marshall, 2007).

Tangible user interfaces offer several potential advantages for learning. They support direct interactions by groups of collocated participants (Marshall, 2007). They afford direct face-to-face social exchange between students and support communication, collaboration and learning among students. They provide a multitude of input devices that, unlike a traditional desktop computer, can be simultaneously manipulated by multiple users (Birchfield & Megowan-Romanowicz, 2009). As interaction with tangible interfaces is assumed to be more natural or familiar than with other types of interface, they might be more accessible to young children (Marshall, 2007). They can engage children in playful learning and these novel links between physical action and digital effects might lead to increased engagement, exploration and reflection (Rogers et al., 2002).

Johnson-Glenberg, Birchfield, et al. (2014) have suggested that, despite the increase of embodied digital environments, a more rigorous understanding of embodied learning through technology-enhanced learning environments is needed. As such, Johnson-Glenberg and her colleagues proposed a taxonomy of embodiment (Johnson-Glenberg, Birchfield, et al., 2014; Johnson-Glenberg, Savio-Ramos, & Henry, 2014; Johnson-Glenberg, Megowan-Romanowicz, Birchfield, & Savio-Ramos, 2016) with current examples of educational technologies composed by four consecutive levels. The degrees of embodiment per level are defined by the following three aspects:

The amount of sensorimotor engagement: Sensorimotor engagement is achieved through locomotion; technologies that provide opportunities for sustained locomotion can facilitate higher levels of embodiment.

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- **The amount of gestural congruency:** Gestural congruency is achieved through the relevance of the gesture with the content to be learned; technologies that provide opportunities for gestures and full-body movement that are linked to the educational content, in ways that reify the learning construct, can facilitate higher levels of embodiment.
- **The amount of immersion:** Even though immersion is a subjective construct, it is also influenced to a great degree by the type and configuration of the content's display. As such, technologies that can provide more surrounding and realistic audiovisual contexts (e.g., virtual or mixed reality technologies), can facilitate higher levels of embodiment through creating an embodied sense of being into the digital world.

These three aspects are used to create a taxonomy based on two possible levels of accomplishment (low or high). The classification is informed by the previous work of Johnson-Glenberg, et al., (2016) and shown in Table 1.

Table 1. The taxonomy of technology-enhanced learning environments according to their affordances for embodiment based on the three aspects

	Level 1	Level 2			Level 3			Level 4
Sensorimotor	L	L	L	H	H	H	L	H
Gestural Congruency	L	L	H	L	H	L	H	H
Immersion	L	H	L	L	L	H	H	H

*H: High / L: Low

In the two lowest levels of the taxonomy (Level 1 and Level 2), embodiment is very limited to non-existing (Johnson-Glenberg et al., 2014a, 2014b, 2016). In particular, the first two levels include desktop-based simulations or videos that are often passively viewed, thus providing no opportunities for sensorimotor engagement. They are also usually realized in small displays, such as computer monitors or tablets, which cannot be perceived as immersive. Finally, in these two lowest levels, interactivity and movement are also very restricted as the input devices for desktops are usually the mouse and the keyboard, while in case of tablets and handheld devices the gestures are also limited (e.g., a finger swipe to advance). As such, the gestural congruency is not a defining construct in the lesson, neither there is a contribution of movement for the reification of the educational content. Due to their limited alignment with their embodiment learning approaches these types of technology-enhanced learning environments are out of the scope of the present review.

In contrast, in the two upper levels of the taxonomy, embodiment is observed at much higher degrees (Johnson-Glenberg et al., 2014a, 2014b, 2016). In particular, in the upper levels hand gestures or even the whole body could be used, as the technology-enhanced learning environments are equipped with motion tracking systems (e.g., Wii, Xbox Kinect, or Leap Motion). They also usually include large screen displays, floor projections, or even 360° head-mounted displays (HMD), virtual reality and mixed reality rooms, which are perceived as highly immersive. Importantly,

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gestural congruency is in most of the cases a defining aspect of the embodied learning experience as hand gestures or body movements are closely mapped to educational content that must be learned. Due to their high alignment with their embodiment learning approaches the technology-enhanced learning environments included in the two upper levels of the taxonomy are the ones included in the scope of the present review.

From the technologies in these upper two levels, motion-tracking devices, such as Wii[1], Kinect[2] or Leap motion[3] have attracted the attention of experts in the field of special education (Ojeda-Castelo, Piedra-Fernandez, Iribarne, & Bernal-Bravo, 2018). These technologies, which enable natural interaction, allow special needs' students to interact using speech and gesture recognition detection. Full body interaction is more convenient for students that are not able of performing fine-grained gestures, such as the ones required by tablets and mice.

Ojeda-Castelo et al. (2018) analyzed Kinect against similar technologies, and chose this technology due to its accuracy in identifying the body movements, the existence of an open API, the voice-recognition and RGB camera, and the fact it does not need calibration. Moreover, Kinect was relatively affordable, and cheaper than other specific technologies that are used in special education. These reasons may explain why (as it will be seen in the following section) most of the applications based on the idea of embodied interactions that are proposed for educational use have been based on Kinect. In fact, this interest may explain why, in spite of the fact that Kinect has been definitively discontinued as a commercial product by Microsoft in 2017, its technology is being considered within Microsoft Azure, in the project "Kinect for Azure" that reportedly aims at combining artificial intelligence with Kinect features (Microsoft, 2018).

4. Learning benefits of embodiment – Empirical evidence

This section provides a review of existing empirical evidence on the learning benefits (or lack thereof) of embodied learning. We provide a brief overview of the main studies that have addressed the topic without focusing on special education, and then the section goes on providing a more exhaustive account of existing studies and the evidence they provide regarding the impact of embodied learning in children with special education needs.

4.1. Studies of embodiment and learning

Body sensory technologies provide new avenues to monitoring learners' body movements and gestures, and enable learners to interact with instructional interventions via motors or haptic customs. Based on these assumptions, Xu and Ke (2014) review existing works applying this perspective and propose a "*motorpsycho*" learning approach based on empirical illustrations and theoretical underpinnings for the gesture-based or motor-based learning enabled by Kinect sensory technology.

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[1] http://wii.com
[2] https://en.wikipedia.org/wiki/Kinect
[3] https://www.leapmotion.com

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SMALLab work constitutes the most systematic research in a formal educational setting concerning the learning benefits of embodiment. SMALLab - Situated Multimedia Arts Learning Lab (in Arizona State University) is a mixed-reality environment where collaboration, interaction and learning take place via full-body and 3D movements along with sonic and visual media in an open physical space. SMALLab's main emphasis has been on creating a variety of interactive games, aimed at enhancing embodiment and on engaging children in new ways of thinking. Students use a trackable object, called "wand" that allows the physical body to function like a 3D cursor in the interactive space. Multiple students can be tracked simultaneously while engaging with the environment while the rest of them stand around the open periphery of the active space and collaborate with each other and with the active students (Johnson-Glenberg, Birchfield, et al., 2014). Studies by SMALLab indicate that there are significant achievement gains and therefore positive impact on collaborative learning when students can work with their whole body in mixed reality environments compared to traditional learning (Johnson-Glenberg et al., 2011).

A few more good examples of embodied learning games can be found in the literature. Human SUGOROCU is a simulation game that consisted of a full-body interaction system to enable elementary school students to enjoy and learn vegetation succession (Adachi et al., 2013). The study was conducted with 27 elementary students (age: 11–12 years), who played the game in two conditions: as a tablet game with touch panel interface and as a human SUGOROKU where students themselves moved on the board as pieces and played the digital game. The results indicated that the full–body interaction promoted a sense of immersion in the game, but no other learning benefits were mentioned. Sound Maker is an interactive sound making environment. It was used in a comparative study to explore the potential benefits of using embodied interaction to help children learn abstract concepts related to musical sounds (Antle et al., 2008). Forty children, aged 7 to 10, participated in the study and learned to create musical sound sequences using this interactive sound making environment. Half the children used a version of the system that instantiated a body-based metaphor in the mapping layer connecting body movements to output sounds. The remaining children used a version of the same environment that did not instantiate a metaphor in the mapping layer. The results provided evidence that children may be able to physically perform sequences better than they can verbally explain them (Antle et al., 2008).

Moreover, iGameFloor is an interactive floor platform for games and learning applications. The platform had been implemented in Mollevangskolen school in Aarthus, Denmark, in the school department square where pupils spend both learning time and break time. A number of learning applications had been developed for iGameFloor, categorized as collaborative learning games, knowledge sharing applications and simulations (Grønbæk et al., 2007). Preliminary analysis of the observations brought about some general lessons regarding kinaesthetic interaction and its relation to learning environments. Initial result indicated that kinaesthetic interaction stimulated collaborative learning and was fun and motivating. Furthermore, Hashagen et al. (2009) developed an installation in a lab that encompasses tangible learning under the name "Der Schwarm". The leading question of their research was whether bodily engagement support children in learning abstract models better than traditional software applications. They conducted and evaluated the study during a workshop with children aged 9-10 years. To contrast, they developed a traditional software application "Boids Regeln" for children to access an abstract model. Based on qualitative data, the authors found that children had a very high motivation to learn about underlying concepts when they interacted with Der Schwarm, whereas Boids Regel superiorly supported students' progress in gaining deeper understanding about the abstract concept of swarm behaviour simulation (Hashagen et al., 2009). In another work, Cress et al. (2010) had track apparent learning gains using a digital dance mat as input devise in their numerical skills training program for kindergarten children which employed a spatial embodied training method. The researchers used data logs of the performance to evaluate learning to assess improvements in accuracy and performance time between the first and second use of the application. Their study with 19 kindergarten children revealed a significant interaction between training condition and repeated exposure to items, implying that children improved more strongly in the dance mat than in the control condition.

4.2 Studies of embodiment and special education

In this section we present an overview of the studies that have applied embodied interaction to children with motor impairments, different levels of ASD, and other kinds of disabilities. Then, we discuss the evidence provided by the reviewed works.

4.2.1 Embodied technologies applied to children with motor impairments

Persons with motor disabilities experience limitations in fine motor control, strength, and range of motion. As pointed out by Ojeda-Castelo et al. (2018), natural interaction, like the one facilitated by body gesture technologies, works well with physically-impaired persons (Chang, Chen, & Huang, 2011). There are many applications that use touchless interaction devices to train the body (Staiano & Calvert, 2011). However, these applications need adaptations to be used by persons with special education needs. For example, it is necessary to include methods, such as games, that motivate the children to interact with the system and persist in the therapy (Kosmas, Ioannou, & Retalis, 2017).

Table 2 summarizes the studies found in the literature where embodied technologies were applied to children with motor impairments. As it can be observed in the table, the dominant technology supporting these games is MS Kinect. As observed by Ojeda-Castelo et al. (2018), Kinect is more convenient for these students than touch interaction. The main reason is that students with motor impairment are not able to perform precise gestures as they handle a tablet or other mobile devices.

Some of the reviewed approaches are oriented to physical rehabilitation, such as Kinerehab (Chang et al., 2011), which detects the user's joint position, and uses the data to determine whether the students' movements have reached the rehabilitation standards in a therapy session. Other proposals focus on the close interleaving between physical and cognitive skills and aim at developing both aspects, like KiNEEt4, which is composed of two modules; a coordination module for developing physical skills and an activity module which aims to improve cognitive skills (Ojeda-Castelo et al., 2018), and Kinems[5], a Kinect-based application that includes a set of games focused on different physical and cognitive capacities. Altanis, Boloudakis, Retalis, and Nikou (2013) and

[4] KiNNEt website, http://acg.ual.es/projects/KinectClassroom/ (last access 28-03-2018)

[5] Kinems Inc. website, http://www.kinems.com (last access 28-03-3018)

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Kosmas et al. (2017) report on studies that applied Kinems to children with different levels of motor impairments.

All the reviewed authors underline the need of adapting the affordances provided by Kinect to the needs of the children, and include different levels of adaptation in their tools. Following this idea, Bossavit and Pina (2014) propose a technological framework that allows to adapt the system to the needs of different children by creating a profile of the users, based on their capabilities with three different small-scale activities with the system. Also, the aforementioned KiNEET and Kinems include specific features to adapt the system to the user.

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Table 2. Review of studies of embodied technologies applied to children with motor impairments

Authors	Technological support	Disability	Methodology	Empirical evidence
Altanis et al. (2013)	Kinems (Games Uni_Paca_Girl and Farm)	Children with dyspraxia and motor impairments	Case study with 2 children. Data source: Observations Variables: • Time and number of attempts for doing a hand movement along a path. • Instability of the students' hands (examined by measuring how many times a student drove the game character to the edges of the path).	• Kinect game can contribute to the synchronization of the hand's physical movement with the eye's visual perception and focus. • Children were able to perform more movements. • Children were in good mood, thus keeping their muscles relaxed, leading to positive effects when trying to improve motor skills. • Video replay option allowed the teacher to know exactly the way the movement was performed by the student. • Teachers can monitor the child's progress at a specific session or for a period of sessions.
Bossavit et al. (2014)	Kinect	Children with different levels of motor skills problems	Case studies. 6 children + 3 teachers. 2-month intervention. 3 activities developed using the system: painting with the arms, discovering an image, create music. Data sources: • Observations: expressions of emotion, body interaction using the application, understanding and execution of orders, use of the application according to the students' level	• Almost all the children were willing to participate in the activities and followed the orders without complaining. • One child improved the control of his gestures. • Although 5 out of 6 children could interact without great difficulties it is almost impossible to find a device that fits the needs of everybody (Standen et al, 2011).

Authors	Technological support	Disability	Methodology	Empirical evidence
Chang et al. (2011)	Kinerehab for Kinect	Motor impairments	2 students. Study - ABAB sequence: • A baseline (no support of Technology) • B intervention phases (supported by Kinerrehab) • 2 sessions per day. Each session consisted of 3 cycles of 3 movements. Data sources: • Observations and recordings of the sessions. • Number of correct movements counted automatically by Kinerehab using gesture recognition.	• During the intervention phase, the number of correct movements was significantly greater compared with the baseline. • The students were interested in the system and motivated in participating in the rehabilitation. • Reduction of staff intervention.
Kosmas et al. (2017)	Kinems games “Walks” and “River Crossing”	Motor impairments	5 children. 5-month intervention Data sources: • Kinems’ analytics • Teachers' self-reported observations • Teachers interviews	• Psychomotor Ability (Gp) is the ability to perform physical body motor movements with precision, coordination, or strength, operationalized in this study as the motor stability of the hand. • Psychomotor Speed (Gps) is the speed and fluidity with which physical body movements can be made, operationalized in this work as the time for successful completion of the task.

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Authors	Technological support	Disability	Methodology	Empirical evidence
				• Improvement in children's motor performance in psychomotor ability and psychomotor speed. • In sum, analysis of system analytics data from the Kinems embodied learning sessions revealed that children experienced significant gains in (i) psychomotor abilities (Gp) operationalized as stability of hand movement and (ii) psychomotor speed (Gps) oper- ationalized as the time needed to successfully complete the task.
Ojeda Castello et al. (2017)	KiNEEt	Motor impairments and other disabilities	Expert evaluation • Surveys about usability, educational mode and students' behaviour. • Experiment with 4 students during 30 days: duration and number of errors.	Evaluators valued positively the tool although they also provided ideas for improvement The results from the experiment show that every student had been able to complete the different exercises and had also carried out the execution of tasks in less time and with a decline in the number of errors at the end of the evaluation period. Students' performance with the games depended on their condition

4.2.2 Embodied technologies applied to children with ASD

Bartoli, Corradi, Garzotto, and Valoriani (2013) analysed the appropriateness and educational potential of motion-based touchless gaming for children with ASD (Autistic Spectrum Disorder). According to these authors, existing studies reveal that embodied interaction technologies accommodate well to the needs of these children, especially regarding engagement and affective experiences. While in regular children these can be considered as side-effects, for ASD-children, these benefits "*are a learning benefit per se, because of these subjects' deficits in the emotional sphere and the abnormal way they relate themselves to the surrounding world*".

Table 3 reviews existing works where touchless motion-based interaction has been used with ASD children, which are summarized in the rest of this sub-section.

Bartoli et al. (2013) carried out an experiment using a subset of commercially available games with five ASD children and one therapist to test the usefulness of these tools. Boutsika (2013) used "Kinect Adventures" (video game collection of five adventure and sports mini-games) with ASD students to enhance their memory and to push them to greater sociability. Cai, Chiew, Nay, Indhumathi, and Huang (2017) focused on developing a VR learning environment for children with ASD to improve their gestures and interest in comprehending tasks' requirements**.** They explore the way of adapting an immersive room (created for research purposes) to a real class scenario creating a VR lab. Garzotto, Gelsomini, Oliveto, and Valoriani (2014) provide an evaluation of Pixel Balance, a motion based touchless game to promote imitative capability, body schema awareness and social skills. Kandroudi and Bratitsis (2013) focused on the development of pedagogical strategies to enhanced learning through the use of Kinems with children with ASD, and Uzuegbunam, Wong, Cheung, and Ruble (2015) tested the effectiveness of MEBook system to promote social interaction. Mademtzi (2016) explored the effect of the Kinect videogame "Pictogram Room" in the development of sensorimotor abilities in children with ASD.

Malinverni et al. (2017) proposed a framework to design games for children with ASD. They focused on the use of narrative resources and of game design praxis. From their work they derived a set of guidelines and suggestions for future works:

- To promote behaviors related to the social request, it is advisable to design cooperative game mechanics where different resources are distributed among the players to achieve a common goal.
- Game mechanics that use physical contact should be avoided so they may hinder social communication by promoting an instrumental use of the other player.
- To facilitate social initiation, potential solutions can be found in the use of surprising and unexpected elements.
- To promote exploration and avoid repetitive behaviors, relevant design solutions can be found in the use of "peephole" strategies.

Table 3. Review of studies of embodied technologies applied to children with ASD

Authors	Technology support	Disability	Methodology	Empirical evidence
Bartoli et al. (2013)	Mini games commercially available for Kinect selected from 150 games.	Children ASD (low-moderate cognitive deficit)	Five children and 1 therapist. 2'5-months intervention. 5 games. Data sources: • Standardized therapeutic test (attention) • Observations during game sessions + Video analysis of children' activities (behavioural and emotional variables and their signals)	• The findings of the study provide empirical evidence that motion-based touchless games can promote attention skills for autistic children with low-moderate cognitive deficit, low-medium sensory-motor dysfunction and motor autonomy. • Improvements in the attention level. Students became able to engage in autonomous play. • Positive results in the emotional sphere.
Boutsika (2013)	Kinect games (Kinect Adventures)	ASD (moderate)	10 ASD children. 3-month intervention They used a teaching model to foster mnemonic techniques useful for the recall of learning materials	• The paper does not provide empirical data and a method for the assessment of the students' progression. • The expected results are that the students will gradually become familiar with the learning data and ideas, will increase the feeling of self-esteem, self-understanding, autonomy and independence.

Authors	Technology support	Disability	Methodology	Empirical evidence
Cai et al. (2017)	Kinect Immersive room	ASD	5 children with ASD Comparative study: immersive room vs virtual learning game The objective was to compare two different technological setups	• VR immersion: an immersive room is good for a middle size group of people. The VR lab with a single flat screen provides basic immersive experience for a small group of children. • VR interaction and interface: Limitation of Kinect, the gesture recognition in the immersive room can become inaccurate or less sensitive when too many people are in the room. • VR modelling is almost the same in both scenarios. However, the VR lab is more scalable. • The game used in the immersive environment was impossible to adapt to the VR lab. However, the new version was better integrated into the regular curricula for SEN children.

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Authors	Technology support	Disability	Methodology	Empirical evidence
Garzotto et al. (2014)	Pixel balance. Kinect game	ASD	DBR Exploration: analysis and comparison of children playing with and without motion based touchless technology. • Observation. 2,5-month intervention. 15 children playing with 5 games. • Videotaped sessions • Focus group with professionals Pixel balance creation and test with 5 children 3-month intervention -Observations	• Improvements in terms of game play autonomy and performance, enhancement of motor skills and positive effects in the social sphere. • "Pixel Balance" positively promotes the development of self-awareness and self-regulation, imitation skills, and the capability of planning body schema and postures.

Authors	Technology support	Disability	Methodology	Empirical evidence
Kambouri (2016)	Kinems	ASD	6 teachers, 7 children 10 weeks Data sources • Teachers notes, • Observations, • Final interviews, • Kinect analytics Students performance (success rate) between sessions	• Children were focused and motivated while playing. • Teachers' considered the tool as simple to use and a good assessment tool.
Mademtzi (2016)	Kinect "Pictogram Room"	ASD	5 children 9 weeks, twice a week, 15 minutes Control group (following year).	• Improvement of the sensorimotor abilities in the children that participated. • Positive results in adaptive behaviour and social game.
Malinverni et al. (2017)	Kinems Pico's adventure	High-functioning children with ASD	10 children with ASD Data sources: • Field observations, • Video analysis. Several behaviours associated with social interaction were observed	• The game works as a mediator of social interaction, and allows to scaffold social interaction with somebody (i.e., caregiver, another child). • Relies on the design of game experiences that are valuable for the child to feel the need to communicate or that require the child to look for external collaboration.

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Authors	Technology support	Disability	Methodology	Empirical evidence
Uzuegbunam (2015)	MEBook. Kinect	ASD	3 children Pre-post test Multiple base line design supported by Single Subject Design approach (SSD). Recording (responses to others' greetings)	• Preliminary evidence of the effectiveness of MEBook on establishing social behaviour. The study highlights the therapeutic value of self-images. • The study shows new ways of combining technology and evidence-based practices such social narratives (the program shows the learner with other peers or adults and various greeting scenarios with animations of the child/or other characters waving, speaking or engaging on the appropriate greeting behaviour).

4.2.3 Embodied technologies applied to children with other common disabilities

The potential benefits of touchless interaction in special education have led the experts to explore them with different types of disabilities, apart from the ones related to motor impairments and ASD, already reviewed in the previous sections. Table 4 provides a summary of these works.

Fu, Wu, Wu, Chai, and Xu (2015) focused in assessing to what extent a game system for rehabilitation based in Kinect is effective for children with mental retardation. They developed and tested a Kinect game for rehabilitation with five different modules: mental rehabilitation, basic perceptual and cognitive program, upper and lower limbs rehabilitation and leisure/healthcare.

Altanis, Boloudakis, Retalis, and Nikou (2013) conducted a one-month intervention study at the premises of the ADHD unit of a children's university hospital; 11 four-eight years old ADHD children played a series of Kinect-based educational games demonstrating significant improvement on their executive functions and cognitive skills (Retalis et al., 2014).

In the context of inclusive education, a study by Kourakli et al. (2017) examined 20 elementary children with special educational needs attending mainstream schools with special units, using a suite of commercial Kinect-based interactive educational games, namely the Kinems suite. Their analysis of data gathered via pre-post testing, interviews, and kinetic/learning analytics showed that the Kinems games had a positive impact on children's academic performance, cognitive, and motor skills.

Last, the study by Kosmas, Ioannou, and Retalis (2017) (see Table 2) examined the use of a series of Kinect-based educational games by 31 children in special education, during a five-month program, and found gains in short-term memory ability as well as positive outcomes related to children's emotional' stage.

Table 4. Review of studies of embodied technologies applied to children with different types of disabilities: mental retardation, common learning disabilities and ADHD

Authors	Technology support	Disability	Methodology	Empirical evidence
Fu et al. (2015)	Kinect game for rehabilitation with five different modules: mental rehabilitation, basic perceptual and cognitive program, upper and lower limbs rehabilitation and leisure/healthcare.	Mental retardation	112 children. Training plan for each child. 1-month intervention Pre-post tests using the Pediatric Evaluation of Disability Inventory (PEDI) (measures self-care, mobility and social function)	• Post tests show that the PEDI score of children is significantly higher than the score before training ○ Greatest progress in social function, followed by self-care, and the smallest progress in mobility. • Trainers were able to adapt each training path to the needs of each student.
Kourakli et al. (2017)	Kinems	Comorbid learning disorders: dyslexia, dyspraxia dyscalculia and ADHD	20 children. Two primary schools Pre-post test (Kauffman assessment battery for children: recall number, recall word, conceptual thinking and expressive vocabulary) Teachers' interviews Kinetic analytics	• Kinems games had a positive impact on children's academic performance and improvement of their cognitive, motor and academic skills.
Retalis et al. (2014)	Kinems	ADHD	11 children 1-month intervention (2-3 sessions/week) Pre-post tests: problem solving, visual attention, concentration, intelligence Teachers' observations Kinetic analytics	• Improvement of non-verbal intelligence. • Improvement of the executive functions and cognitive skills. • Improvement of concentration and attention (results aligned with, Bartoli et al. 2014; Altanis et al., 2013) • High motivation

4.2.4 Summary of collected empirical results

The studies described in the previous sections offer different levels of evidence about the effectiveness of motion-based embodied interaction applied to SEN children. Most of the reviewed works are case-studies carried out with a small number of children, ranging from 2 to 10, that are treated using the tool during a period of time that goes from some days to several months, accompanied by a therapist that has adapted the treatment to the needs of each child. One exception is the study by Fu et al. (2015) that involved 112 children and used pre-post testing to measure the results.

Most of the evidence collected in these case studies is based on the observations made by the therapists or by external observers during the application of the treatment. These observations are combined with other sources of data, such as the data registered by the systems, like in Altanis et al. (2013). There are few exceptions that apply experimental strategies to compare the results of the children with and without intervention, like the ABAB experimental design by Chang, Chen, and Huang (2011), and some works that use a pre-post test design approach, like Fu et al. (2015).

Regarding the results, different kinds of aspects are considered, depending on the focus of the study. Below we present a summary of the main ones found in the reviewed works:

Motivation: Many of the reviewed studies observe a positive influence in the motivation of the children. For children with disabilities, having a higher motivation is a goal in itself because it leads to a higher engagement, and therefore, to better results. For example, (Altanis et al., 2013) reports on a case study with two children with motor impairments using a Kinems game. According to the observations made by the therapists, the children were so engaged in playing the game that they overpassed their fatigue or difficulties in physical movements. Similar results are reported by other studies with children with motor impairments, like Bossavit and Pina (2014), Chang et al. (2011), and with children with ASD (Kambouri & Tsiakalou, 2016).

Attention: Existing studies state that the positive effects of motion-based games on engagement create an emotional state that facilitates attention and concentration. For example, in Bartoli et al. (2013) the overall gaming experience seemed to promote stronger incremental results for children with low levels of attention skills, and Retalis et al. (2014) observed and improvement of concentration and attention in children with ADHD.

Motor skills: As described by Altanis et al. (2013), the application of the Kinems game contributed to the synchronization of the hand's physical movement with the eye's visual perception and focus. The students managed to perform the exercises with the games with much less effort than the effort spent doing the same exercises in a typical therapeutic way. In the study by Chang et al. (2011), which used an ABAB design, it was observed that during the intervention phase, the number of correct movements was significantly greater compared with the baseline. Finally, the study by Kosmas et al. (2017) revealed improvements in children' motor performance in psychomotor ability and psychomotor speed.

Emotional space: Some studies focus on factors in the emotional space, which are of special interest in children with ASD. For example, the study by Bartoli et al. (2013) involved five children with autism. The results inform on the learning benefits concerning factors in the emotional and behavioural space: distress (the sense of mental or emotional suffering and anxiety), positive emotion, need for intervention agency (autonomy), usability gap (correctness of actions with respect to game logic and interaction rules). Kambouri and Tsiakalou (2016) also report on benefits in this area.

Social sphere: Together with emotional factors, social behaviour is of great importance in children with ASD and some benefits have been observed by different works.

Malinverni and Pares (2014), Uzuegbunam et al. (2015), Mademtzi (2016) and Garzotto et al. (2014) report on preliminary evidence of the effectiveness of the Kinect-based games on establishing social interaction, and a positive attitude toward social play with peers. More concretely, Malinverni and Pares (2014) relies on the design of game experiences that require the child to feel the need to communicate or to look for external collaboration. Uzuegbunam et al. (2015) combined social narratives, video self-modeling and digital learning games to create MEBook, an interactive social narrative tool to promote social interaction in children with ASD with the support of Kinect. Mademtzi (2016) observed impromevents in the social game and adaptive behaviour of the children that had participated in their intervention with Kinect-based game “Pictogram room”. Garzotto et al. (2014) noted that the bidirectional eye triangulation that occurs during play between the child, the therapist and the game screen, which can be considered a form of social interaction, was repeatedly noticed. Fu et al. (2015) studied the effects of a Kinect-based therapy on 112 children with mental disorder, with pre-post evaluation using the Pediatric Evaluation of Disability Inventory (PEDI), measuring self care, mobility and social function. The observed significant improvements in all of these measures.

Academic performance: A small number of studies has taken place in inclusive classroom settings, with a medium number of children (around 20) and have taken into account several measures of academic performance.

Kourakli et al. (2017) carried out a pilot research study in 2 primary schools with 20 SEN children with special educational needs using Kinems. Using pre-post testing, they measured recall number, recall word, conceptual thinking and expressive vocabulary, using interviews and Kinems’ analytics. The result shown a positive impact on children's academic performance and improvement of their cognitive, motor and academic skills.

Retalis et al. (2014) carried out an intervention to evaluate the effectiveness of the Kinems learning games for helping children with Attention Deficit Hyperactivity Disorder (ADHD), and observed an improvement of the executive functions and cognitive skills.

Tools’ functionality and usability: Based mainly on the observations made by the therapists or teachers themselves, many of the studies report on the potential benefits of the tools for providing a better support to the children. Altanis et al. (2013) observes that with the use of the evaluated tool, teachers can monitor the child's progress at a specific session or for a period of sessions. More specifically, the *video replay* option allowed the teacher to know exactly the way the movement was performed by the student. Chang et al. (2011) observe a reduction in the need of staff intervention due to the use of the tool, and Kambouri and Tsiakalou (2016) stress the possibilities of using the reporting capabilities of the tool they used (Kinems) to help teachers in assessing the progress of the students.

Overall, it can be seen that the studies are positive regarding the possibilities of these technologies. However, findings are not fully conclusive. A few researchers have commented on the lack of solid empirical evidence to support these assumed benefits (Schneider et al., 2011; Malinverni & Pares, 2014; Price et al., 2008; Xie et al., 2008; O'Malley & Fraser, 2004). Little is also known about what kinds of embodied interaction can afford which cognitive processes and what kinds of interactivity can be facilitated by embodied technologies.

5. Conclusions

This report has presented an overview of current research regarding the application of embodied technologies to the learning of SEN children.

The report has explored the main concepts associated to the theory of embodiment and its connections with related areas, such as kinesthetic learning and situated cognition. The goal of this part of the review is to clarify the theoretical framework underlying the project, and to identify the areas related to this theory.

Secondly, the report has clarified the kind of technologies that will be considered in the scope of the project. Based on the classification provided in Section 3, motion-based body-gesture technologies appear as the best suited to implement the principles of embodiment. These technologies are represented by commercial products such as Wii, Leap Motion and Kinect. Among these three, the review has shown that the latter is the preferred choice by the works that aim at applying embodied learning for the treatment of children with SEN.

A crucial aspect of the work regarding the application of these technologies in educational contexts is whether there exists evidence of their benefits for learning. The last part of this report has focused on reviewing existing research on that aspect. The work carried out shows initial evidence of the benefits that motion-based interaction games on aspects such as motivation, attention, emotional and social dimensions, and cognitive improvement. However, this evidence is mostly based on observations made in small-scale case studies, or initial pre-post testing in small groups, and many questions remain unanswered about the reasons of the observed positive effects.

Therefore, further work is needed to explain clearly how the body can influence cognition and how the body becomes necessary in cognitive work (Glenberg et al., 2013). Particularly, in education it is essential to examine how technologies could be integrated into classrooms and which is the best way to design and prepare learning environments that take full advantage of embodied learning (Evans & Rick, 2014). That is, additional research is needed to investigate the value of most current technologies and to examine the role they might play in facilitating embodied learning pedagogies in formal educational environments. Also, studies should focus on teaching and learning investigating how designers can build new understandings of embodied cognition in learning environments (Hall & Nemirovsky, 2012). Empirical research is limited also in the field of embodied interactive games for healthcare and special education (Altanis et al., 2013). Last, research needs to investigate effective ways for teachers to know how to use and adopt technologies, which provide the bodily engagement in the learning environment (Price, Roussos, Falcão, & Sheridan, 2009).

All things considered, taking into account the theories arising from embodied cognition, developments in computing technologies, and evidence from research, the future for education is set to change. Embodied learning is an exciting and interesting area of investigation (Lindgren &

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Johnson-Glenberg, 2013), because of the many existing challenges related to learning design and technology in various domains and contexts. Abrahamson (2013) claims that embodied learning requires a pedagogical framework for the creation of environments in which learners can be guided to work together, interact, move and play under inquiry situations. Additional research is needed to investigate the potential value of emerging technologies under the umbrella of EC. A pedagogical framework is needed for illustrating the use technologies as embodied learning tools, allowing learners to actively engage mind and body in the learning processes. Overall future studies should aim at the following goals:

- to examine how embodiment through the means of technology may have an impact on the learning process
- to gain better understanding of design issues and learning conditions for enacting EC theory in the classroom using technology.
- to document how embodied learning using technologies might be a venue to inclusive design and learning design for all.

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