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From psychomotor to 'motorpsycho': learning through gestures with body sensory technologies

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Abstract As information and communication technology continues to evolve, body sensory technologies, like the Microsoft Kinect, provide learning designers new approaches to facilitating learning in an innovative way. With the advent of body sensory technology like the Kinect, it is important to use motor activities for learning in good and effective ways. In this article, we aim to examine both empirical illustrations and theoretical underpinnings for the gesture-based or motor-based learning enabled by the body sensory technology. We review and distill salient concepts and ideas from the existing theoretical and empirical literature related to body-movement- and gesture-based learning, and propose a *motorpsycho* learning approach. In our discussion, the word/affix *motor* is synonym to gestures and body movements, and *psycho* is synonym to cognitive activities. We explore the important role that motors play in psychological activities, especially in cognitive learning. We argue that motors can facilitate psychological activities in learning by enhancing information processing, encoding, representing, and communicating. We also call for more empirical studies on technology-enhanced and gesture-based learning to design, practice, and examine the motorpsycho learning approach.

Keywords Motorpsycho · Learning · Gesture · Kinect

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Introduction

The recent development of 3D body sensory technologies, such as the Microsoft Kinect, has greatly inspired designers and researchers across technical and educational fields. Some Kinect-based educational applications are shared informally among the community (e.g., Chambers 2011; Hachman 2010; Kissko 2011; VanderVen 2012). However, theoretical research is limited in these applications with regard to the underlying cognitive theories and learning approaches. It is hard to find published journal articles that are directly related to learning activities with 3D body sensory technologies. Little research is published on the design or the effectiveness of Kinect-integrated, gesture-based learning due to the newness of 3D body sensory technologies. Although studies highlighting the relationship between body movements and learning exist, there still remains a dearth of empirical studies on learning environments employing body sensory technologies. Theoretical foundations are also scarce in supporting sensory-technology-enabled, gesture-based learning. In this conceptual analysis article, we explore both empirical illustrations and theoretical underpinnings for the gesture-based learning enabled by the body sensory technology. The exploration is driven by a systematic review of the literature on gesture-based learning, movements and cognition, and enriched body interaction with the computer. By analyzing and synthesizing the previous research findings and theoretical discussions, we argue that cognition can be situated in, encoded by, and externalized via physical movements and body gestures via a purposefully designed, motorpsycho learning approach.

From psychomotor to motorpsycho

In Bloom's (1956, 1994) taxonomy, learning can be categorized into three aspects—Cognitive, Affective, and Psychomotor. Our discussion starts from psychomotor skills which, according to Bloom (1956, 1994) and Simpson (1972), refer to the learning outcomes that involve physical movement, coordination, and use of the motor-skills. Notably, in the word of psychomotor, *psycho* goes first and *motor* follows. It shows an assumption on the direction of how cognition and movement is achieved. It is commonly believed that as primates, we humans frequently use our brain and neurons to pass orders to our muscles and skeletons to act and perform. In such a context, cognitive knowledge directs the execution of our performances.

Based on a review of prior research on cognitive science and learning, in this conceptual article we would like to argue for a *motorpsycho* approach for learning, in which body movements and gestures help learners acquire cognitive knowledge. With the advent of the body sensory technology like the Kinect, it is important to incorporate motor activities for learning in sound and effective ways. We expect that our proposed motorpsycho approach will help researchers to understand the ways motor activities affect people learn, teach, and communicate. The proposed approach should be considered as an interpretive, conceptual framework for the design and research of active, gesture-based learning with the help of the body sensory technology.

In biology and neural science, the term motor, or motor system, often refers to the part of brain or neural system that is related to physical movements (Rizzolatti and Luppino 2001). In learning science and sports psychology, motor skills are combinations of learned body movements that serve specific tasks (Leeds 2007; Luft and Buitrago 2005). In communication science and also learning science, a gesture is a movement of the limbs, face, or other parts of the body that accompanies verbal or non-verbal communications

(Roth 2001). In other words, gestures refer to “a variety of movements—including movement of hands and arms, adjustment of posture, the touching of oneself” (p. 368). Gestures may originate from instructors or from learners themselves. The commonness among the concepts of motor, motor skills, and gestures across disciplines is that they all involve body movements. Conceptually, motor activities have a broader extension in meaning than gestures, and the latter can be part of motor activities. Since gestures and learning are actively studied by researchers in the academic community, in this article we employ gestures as an anchor point for discussing motor activities at large. In the following texts, the word/affix *motor* is synonym to body gestures/movements and motor activities, and *psycho* is synonym to mind activities and cognitive learning.

Motors and psycho-activities

Cognitive information processing theory argues for three kinds of memories—sensory, working, and long-term memories (Atkinson and Shiffrin 1968; Baddeley and Hitch 1974; Driscoll 2005; Richey 1986). In light of this theory, it is desirable to design instructions that capture learners’ attention for their sensory registers to pick up relevant information, and that scaffold learners when they process and encode the information to form links connecting their working and long-term memories. A body sensory tool such as Kinect, by capturing the learner’s body movements, provides an innovative and affordable way for a learner to interact with the computer. Moreover, a designer may design adaptive human–machine interactions tailored for a particular application. Thus different gestures may be assigned to different actions in a computer-based instruction to embody varied content knowledge and to regulate the instruction and learning process. In other terms, the involvement of gestures or motor activities, via body sensory technologies, may foster and retain concentration and learning engagement.

In the discussions to follow, we argue that motor activities further facilitate psycho-activities by enhancing information processing and enabling cognition communication and representation. We first introduce how we collect, select, analyze, and synthesize the literature. We then elaborate on the motorpsycho approach by discussing two major roles of motors in psychological activities—facilitating information processing, and enhancing information presentation and communication. The discussion is based on a comparative analysis of 31 selected representative studies, as well as other reviews and theoretical analysis papers. Third, we briefly describe the state-of-the-art situation in learning with body sensory technologies. We end this paper with a summative discussion on the design and research implications.

Procedure of literature review and synthesis

It is the promising vista of body-sensory-based educational applications that motivates us to explore the role that motor plays in learning cognition. Because of its novelty, and the lack of empirical and theoretical studies on the body sensory technology and learning, we refer to the literature on gestures and cognition in general. We have used “body movements”, “gestures”, “Kinect”, “learning”, “education”, “cognition” and their combinations as the keywords when searching related publications. The databases we used were ERIC, JSTOR, IEEE Xplore, and Web of Science. We also used the Internet search engines like Google and Google Scholar to search ongoing programs and projects applying body sensory technologies. At the same time, comprehensive review articles on related topics also inspired our searching of publications and elaboration of arguments (e.g., Hostetter 2011; Roth 2001). We referred to the literature in the 1990's and late 1980's while concentrating more on the contemporary research studies within this century. Publications we included in this paper were from peer-reviewed journals and conference proceedings.

Among the studies reviewed, 31 were selected as the exemplary studies to inform on the motorpsycho research and were listed in Table 1. They met at least one of the following criteria: (1) studies on learning and cognition related to the application of the body sensory technology; (2) studies on body-movement- and gesture-based learning interventions with and without human–computer interaction; and (3) studies on gestures/movements and cognition.

Publications reviewed have worked as the foundation for our discussion of the motorpsycho approach. Studies selected consist of experimental, quasi-experimental, and case studies. A set of salient themes emerged on how previous studies had defined and used motor activities during learning and psychological processes. These themes were then further refined and synthesized to contribute the major categories on the role of motor activities for learning (see Table 1). The M→P symbol in the first column of the table highlights a proactive role that motors play in psycho-activities, which does not necessarily indicate a causal relationship. The M←→P symbol highlights a mutual and interactive association between motors and psycho-activities. Notably, a single study may focus on one or multiple roles of motor activities. These studies, as well as other reviews and related theoretical articles, were cited in our discussion on how motor activities facilitate information processing and communication.

Motors facilitate information processing

In this part, we review and analyze the prior research to illustrate that motors can facilitate information processing for conceptual understanding and knowledge acquisition, particularly by attracting attention, enhancing information encoding and concept concretization, reducing cognitive load, and offering multimodalities.

Motors attract attention and enhance information encoding and concretization

A summary by Barsalou (2008, 2010) on the grounded cognition argued that experience and cognition were grounded in actions and movements, such as simulations, situated actions, or states of body gestures. It suggested that embodying body gestures and movements in teaching and learning should activate learners' cognitive processing of abstract concepts. In particular, a learner's former actions or movements (e.g., that of using a tool) may trigger the perceptual understanding and help the fusion of perception and action (Mizelle and Wheaton 2010). Hence the specific physical actions of tool or object operation can be used to encode or represent this tool or object. For example, when thinking about a saw, the actions and movements using a saw to cut the wood or metal will encode one's perception on the functionality of a saw. Body movements and actions also prompt us to recall our prior experiences and cognition, link them to the current situation, and reapply them for future actions and understanding (Barsalou 2010; Mizelle and Wheaton 2010). As such, comprehension and abstract cognition may emerge from body movements, and learning may be a post-kinetic phenomenon. Body movements thus act as the foundation of people's know-how (Bautista et al. 2011).

Table 1 A summative table on how motors facilitate information processing and communication

Category	Author(s) and year	Motor-activities	Psycho-activities	Motor vs. psycho (Relationship)	Why	Learning setting	Learning outcome	Keynotes
Attention attraction and externalization (M→P)	Goldin-Meadow, Cook, & Mitchell (2009)	V-shaped hand gestures grouping two correct numbers together; pointing at the blank where the correct answer should be while doing math calculation	Adding of multiple (three) integral numbers for 3rd and 4th graders	Children required to produce correct gestures learn more than children required to produce partially correct gestures, who learn more than children required to produce no gestures	Information is conveyed in gestures which facilitate learning by helping children extract information from their own hand movements	F2F classroom setting	Math summation knowledge	Grouping and pointing gestures for attention attracting —prioritize and select information that is essential; grouping gestures externalizes the math thinking of summing the right numbers
Attention attraction (M→P)	Lee et al. (2012)	Gestures like hand raising, waving, pointing, etc. which are captured by Kinect	Conversational language learning in a board-game-like learning environment	Gestures have positive relationship with language learning	Interacting and being recognized by the virtual character through gestures let students focus more on learning performance; body motions involved in authentic learning experience can increase joyfulness, which is a positive factor facilitating cognitive activities	HCI (VR-based with Kinect involved)	Language skills in conversations	Gestures gain learners' attention, and serve as another mode of learning experience
Attention attraction (M→P)	Rumme et al. (2008)	Pointing gestures indicating spatial relationships	Learning English as a second language	Pointing gestures draw listener's attention to abstract subject matters	Pointing gestures show audience referents related to spatial information, and draw attention from audience Pointing gestures referring to abstract matters may invite a listener to interpret what a speaker intend to indicate	F2F classroom setting	English language learning	Compared with a laser pointer, pointing gestures bring what the authors called "referential ambiguity" which trigger learners to actively interpret the abstract concepts

Table 1 continued

Category	Author(s) and year	Motor-activities	Psycho-activities	Motor vs. psycho (Relationship)	Why	Learning setting	Learning outcome	Keynotes
Attention attraction (M→P)	Vogel et al. (2012)	Four typical gestures recognized by Kinect – calibrating, swiping, clicking, and swimming	Knowledge about a computer-based interactive map	Such gestures are related to the content knowledge in attracting viewers' attention and in exploring contents in an easy and friendly way	Body gestures capture learners' attention and arouse their attention	HCI (VR-based with Kinect involved) in collaborative exploration	Concept knowledge	Gestures catch viewers' attention and help gathering data (part of data collection process)
Attention attraction, multimodality and concretization (M→P)	Valenzeno, Alibali, & Klatzky (2003)	Pointing, tracing, and comparative gestures when explain the knowledge of symmetry	Understanding of symmetry and symmetrical shapes	Learners may glean more information related to symmetry from teachers' gestures	Gestures capture and maintain learners' attention, provide extra channel to comprehend messages, and concretize the speech in the physical environment	Video lessons played in a testing room	Concept knowledge	Gestures from the teachers reinforce verbal messages, and facilitate linking the concrete and the abstract. Gestures are important in teaching new concept in an instructional setting
Encoding (M→P)	Macedonia & Knosche (2011)	Performing representative gestures while memorizing words	Abstract word learning in a foreign language; sentence production	Word learning is enhanced with symbolic gestures; words with symbolic gestures are more frequently used while making sentences	Symbolic gestures facilitate in encoding information when memorizing; abstract cognition is concretized through gestures	F2F	Foreign language learning(word memorizing and sentence building)	Vocabulary is encoded through motor activities

Table 1 continued

Category	Author(s) and year	Motor-activities	Psycho-activities	Motor vs. psycho (Relationship)	Why	Learning setting	Learning outcome	Keynotes
Encoding, attention attraction, and externalization (M→P)	Aliabali and Nathan (2012)	Pointing,	representational, and metaphoric gestures in math learning	Mathematical concepts and thinking	Mathematical cognition is based in perception and action	Gestures map and transfer cognition, and reflect one's thinking about math concepts and procedures	F2F classroom setting	Conceptual understanding and procedural knowledge in math equation calculation
Knowledge of abstract math is encoded or represented through gestures								
Encoding (M→P)	Mizelle and Wheaton (2010)	(Former) actions of tools using	How to and for what to use the tools	Actions of tool-using help selection of appropriate tools, and controlling mechanism	Actions of tool-using are used to encode a tool/object representation, and to form the states for people to recall while trying to represent related concepts and/or knowledge	Daily setting	Content and procedural knowledge	Actions encode an object with extended information (i.e., a motor-psycho set); such encoding in memory lasts, and may help to retrieve content and procedural knowledge asynchronously

Table 1 continued

Category	Author(s) and year	Motor-activities	Psycho-activities	Motor vs. psycho (Relationship)	Why	Learning setting	Learning outcome	Keynotes
Encoding,			externalization, and multimodality (M→P)	Broaders et al. (2007)	Children are made to gesture while expressing implicit math knowledge	Math	knowledge for 3rd and 4th graders	Spontaneously expressing problem-solving strategies in gesture bring better chance to succeed in math
Gestures provide insight into a level of representation that is neither fully explicit nor fully implicit, which is one of the levels in representing content knowledge	F2F classroom setting	Conceptual understanding and procedural knowledge in math equation calculation	Gestures externalize implicit knowledge, and are one modality that encode and/or express ideas and knowledge					
Encoding and attention attraction (M→P)	So, Chen-Hui, & Wei-Shan (2012)	Iconic and beat gestures associated to verb words	Participants derive meaning from gestures (representing verb words) according to their physical forms and movements	Such gestures support memory recall	Iconic gestures, as the name suggest, enhance memory recall by facilitating the encoding process; beat gestures serve meta-cognitive function by marking the word or concept the speaker would like to emphasize, and changing acoustic properties of speech by modulating activity of auditory cortex during speech comprehension. These led to improvement of memory recalling	F2F	Memory recall on action verbs	Gestures facilitate memory encoding, and serve as meta-cognitive functionality (attention/self-regulation)

Table 1 continued

Category	Author(s) and year	Motor-activities	Psycho-activities	Motor vs. psycho (Relationship)	Why	Learning setting	Learning outcome	Keynotes
Concretization and attention attraction (M→P)	Chang et al. (2013)	Gestures that mimic the typical movements representing eight categories of intelligences, such as musical, interpersonal, and kinesthetic ones, etc., like playing the violin, waving hands to someone, and dribbling a basketball, etc	The college students' retention of those categories of intelligences, which are the content knowledge in the study	Gesture-based presentations show positive impact on the retention of such content knowledge both immediately after the intervention and 4 weeks later than the intervention	Body gestures serve as metaphors representing the taxonomy of multiple intelligences (the content knowledge in this study). Attract attention, enrich knowledge representations, and assist acquiring abstract contents	F2F classroom setting; The gestures are captured by Kinect to trigger different ppt slides show	Conceptual understanding of types of multiple intelligence	Concretizing abstract concept using physical/motor activity; the body gestures also attract attention of the learners'
Concretization (M→P)	Bautista, Roth, & Thom (2011)	Kinetic movements	Abstract mathematical knowledge (geometry)	Learning occurs after the kinectic movements of human bodies	The kinectic movement constitutes a necessary condition for the emergence of abstract mathematical knowledge, and more specifically for the emergence of geometrical insight. Learning acts as a post-kinetic phenomenon	F2F school settings	Conceptual understanding of abstract geometry concept	Concretizing abstract concept using physical/motor activity
Concretization (M→P)	Amorim, Isableu, & Jarraya (2006)	Different body poses	Mental spatial transformations	Body parts are mapped onto the objects to form the mechanism of mental spatial transformations	Body gestures serve as metaphors; spatial information processing is embodied in bodily stimuli	Human Computer Interaction (HCI)	Abstract cognition (e.g. shape matching, and spatial transformation)	Motors (body shapes and poses in this context) concretize abstract ideas

Table 1 continued

Category	Author(s) and year	Motor-activities	Psycho-activities	Motor vs. psycho (Relationship)	Why	Learning setting	Learning outcome	Keynotes
Concretization and encoding (M→P)	Allen (1995)	Emblematic gestures for French learning	Write equivalent English translations/interpretations of certain French sentences	Gestures provide an elaborated context for language learning and retention	Gestures facilitate the binding, mapping and encoding processes of internalization	Classroom setting with TVs	Foreign language learning	Gestures accompanying the language learning process lead to better language recall and less lost
Concretization, externalization and communication (M→P)	Kita & Davies (2009)	Representational gestures while speaking to express abstract ideas	Speeches	More representational gestures are made for harder conditions than for easier ones when speaking	Gestures facilitate conceptualization process for speaking; gestures determine what and how much information is needed in each utterance	F2F	Abstract knowledge (geometry)	Gestures help to externalize the information carried in speeches, and are related to the complexity of content knowledge. Gestures determine what and how much information is needed in each utterance
Externalization (M→P)	Glenberg & Kaschak (2002)	Actions with directions (e.g., toward- and away-the-body movements)	Judgment on the affordance of a sentence	Language understanding is grounded in bodily action	Language understanding derives from the biomechanical nature of bodies and perceptual systems	F2F observations	The action-sentence compatibility effect	Motor activity serves as an extrinsic simulator of the meaning of sentences in a language

Table 1 continued

Category	Author(s) and year	Motor-activities	Psycho-activities	Motor vs. psycho (Relationship)	Why	Learning setting	Learning outcome	Keynotes
Externalization (M→P)	Chui (2011)	Hand and arm gestures related to conversations	Daily face-to-face conversations in the Chinese language	Linguistic metaphors are substantiated by metaphoric gestures	Gestures convey people's metaphorical thoughts, form source-domain concepts, and link linguistic and imagistic representations in daily communication	Video records observations	Natural conversation	Metaphorical gestures externalize what the speaker want to convey in mind
Externalization, multimodality (M→P), and communication (M←→P)	Arzarello et al. (2009)	Move hands or fingers to mimic mathematical graphs; trace at key features on a graph while talking about such features	Sharing math graph features among peers; drawing math graphs in both short- and long-time rounds	Gestures and the math concepts form a semiotic bundle	The role of gestures, which supports the thinking process, is part of the multimodal system for learning Gestures also serve as a communication function among students and instructors	F2F classroom setting	Understanding the features of mathematical functions, and their representations on graphs	Gestures are one of the semiotic resources; govern the production and transformation of various signs and their relationships; externalize math concepts in another modality
Externalization, multimodality and communication (M→P)	Edwards (2009)	A collection of gestures related to the concept of math fractions, such as iconic, metaphoric, beat, and deixis gestures	Conceptual ideas about match fractions	Iconic gesture like cutting, and tangible objects expressing fractions; metaphoric gestures for comparison; "algorithms in the air" evoke fractional concepts	Gestures serve as one modality through which people express what and how they are thinking; gestures map to abstract ideas; gestures evoke elements of written inscriptions	F2F	Expression and explanation of mathematical concepts – the fractions	Gestures are one multimodal representation when expressing abstract ideas; externalize abstract thinking by gesturing; gestures are used to communicate about abstract or general mathematical objects or processes

Table 1 continued

Category	Author(s) and year	Motor-activities	Psycho-activities	Motor vs. psycho (Relationship)	Why	Learning setting	Learning outcome	Keynotes
Externalization and multimodality (M→P)	Sauter et al. (2012)	Body movements indicating spatial information	Communicating spatial information	Gestures are used solely, or together with speeches to convey spatial information. Speeches without gestures are very rarely used	Gestures are important for conveying spatial information; gestures form one modality when expressing abstract knowledge like the spatial information	F2F	Conceptual knowledge (Spatial)	Gestures make communication non-linear; multimodal channels act simultaneously; sometimes gestures are irreplaceable with speech while expressing relational (spatial) information
Externalization, attention attraction and communication (M→P)	Reynolds & Reeve (2002)	Gestures expressing object movements, shapes and angels, and speech tempos and pauses	General concepts about physics – speed and time with regard to a bouncing ball and a school bus in collaborative learning	Gestures are used to judge what content knowledge students are concentrating on, and to judge whether and how much students understand a certain topic	Gestures assist in achieving and maintaining joint-attention, and also act as a cognitive amplifier by allowing students who were unfamiliar with the language of their problem domain to better represent their understanding of abstract concepts	F2F collaborative learning setting	Physical concepts such as speed and time	Gestures serve to externalize and share thinking when learning physical concepts. Cognitive amplifier is a good way to express motors' role of externalization and communication
Communication (M→P)	Bavelas et al. (1995)	Hand gestures while retelling stories	Retell the cartoon video stories shown to the participants in pairs, both in dialogues and monologues	Gestures in conversation illustrate the events, objects, actions, or ideas related to the topic	Gestures deliver information, cite other speakers information, ask for responses from audience, and coordinate the sequence when multiple people are talking	Lab setting with recording devices	Interactive gestures in communication	Gestures help speakers express their ideas and coordinate their communications

Table 1 continued

Category	Author(s) and year	Motor-activities	Psycho-activities	Motor vs. psycho (Relationship)	Why	Learning setting	Learning outcome	Keynotes
Externalization and encoding (M→P)	Shoval (2011)	Physical contact with the learning environment; movements shaping objects, angles, degrees, etc. – Mindful Movements as the author puts	Knowledge about angles for 2nd and 3rd graders	Information known from the kinesthesia of learning is significant. Mindful movements improved learners' achievements; there is a link between number of times a learner performed each of the learning activities and the improvement in his/her achievements	Body movements interact with verbal and cognitive processing	F2F classroom setting	Mathematical concepts about angles	Gestures externalize abstract concepts shown visually and felt kinesthetically; encode an object with extended information (i.e., motor-psycho set)
Indirect externalization through sense of presence (M→P)	Riva (2009)	Actions in general	Sense of presence	Actions and sense of presence are related. A subject is ''present'' in the space—real or virtual—where s/he can act in	Physical being is essential to presence. Action is one of the features of physical being, and is more important than perception when forming sense of presence	N/A	Sense of presence as an extrinsic form of intentions	Actions (motor) transform intentions (psycho), and serve as another extrinsic form of intentions to externalize the sense of presence

Table 1 continued

Category	Author(s) and year	Motor-activities	Psycho-activities	Motor vs. psycho (Relationship)	Why	Learning setting	Learning outcome	Keynotes
Indirect externalization through sense of presence (M→P)	Slater et al. (1998)	Turning heads, bending down, standing up, etc	Sense of presence in a virtual lab	A positive relationship exists between the effect of body movements and presence	Body movements while exploring the virtual environment help to evoke the learners' sense of presence as a virtual experience, which, in turn, induce similar reactions and emotions as a real experience	Tests with HMD (head-mounted device) in VR (virtual reality) settings	Better sense of presence with body movements	Motors probe the sense of presence in VR, and externalize concepts in VR through presence
Reduction of cognitive load (M→P)	Ozcelik & Sengul (2012)	Drawing 3D vectors with body movements in virtual reality with the help of Kinect	Abstract concept knowledge regarding vectors in physics	Such body movements enhance the concept learning by decreasing cognitive load	Gestures reduce the cost associated with the maintaining of information in working memory	HCI (VR-based with Kinect involved)	Understanding of concept knowledge in physics	Motor lightens the cognitive load when abstract information is processed in memory
Reduction of cognitive load and encoding (M→P)	Cook & Goldin-Meadow (2006)	Gestures accompanying mathematic problems for 3rd and 4th graders; Children imitate the problem or create their own	Math problems for 3rd and 4th graders	Gestures have positive impacts on math learning	Gestures reduce the load on working memory system, directly manipulate the online memory processing with new representations, form imagistic representations in memory that could later be retrieved, and bridge the understanding of the relation between the real-world problem and their own mental model of the problem	F2F	Content knowledge in math learning	Gestures lighten the memory load and help encoding information;

Table 1 continued

Category	Author(s) and year	Motor-activities	Psycho-activities	Motor vs. psycho (Relationship)	Why	Learning setting	Learning outcome	Keynotes
Reduction of cognitive load and selection of Information (M→P)	Yu et al. (2009)	Actions related to perception (grasp, touch)	Visual perception	Children select information through their own actions	Actions select visual information and also reduce visual information while processing	F2F	Perceptions and objects recognition	Motoric actions diminish the necessary information to be processed, and moderate the processing
Interaction (M←→P)	Niedenthal et al. (2005)	Bodily states	Social cognition (attitudes, social perception, and emotion)	Bodily states are both effects and causes of social cognition	Interaction with the social environment stimulates higher cognition; body movements help forming and recalling of cognition	N/A	Social cognition: encoding of concept	Interactive relation: psycho and motor are causing/influencing each other
Interaction (M←→P)	Kita et al. (2007)	Gestures associated with speeches, like manner gestures and path gestures	Retell motoric information in the gestures in speeches to others	People turned to employ body gestures with linguistic representations in an interactive online manner	Body movements serve as a part of the mental encoding process	Video played back to participants;	Gesture expressions in speeches	Gestures and languages act in an interactive manner; spatial imagery is packaged into spatio-motoric units
Interaction (M←→P)	Kelly, Özyürek, & Maris (2010)	Gestures both congruent and incongruent with action primes	Speeches; recognition of actions	Gestures and speech play hand-in-hand for mental cognition	When gesture and speech convey the same information, they are easier to understand than when they convey different information; gesture and speech interact mutually to represent content cognition and act in a bidirectional way to convey information. The integration of gesture and speech is obligatory: these two modalities are naturally bundled and people cannot help considering one while processing the other	HCI (videos played back to participants)	Concept knowledge	Consistency of gestures and speeches in expressing/conveying information; gestures and speeches act side-by-side when processing information

Motors and learning

Chang et al. (2013) examined the learning effectiveness of a Kinect-based, multimedia environment for 16 college students' conceptual understanding of verbal information. They used Kinect to capture eight gestures which then were used as the triggers to elicit eight different PowerPoint presentations. Each body gesture served as a metaphor for one of the eight types of intelligences, such as musical, interpersonal, and kinesthetic intelligences (the targeted content knowledge in the study). These gestures, captured by Kinect, mimicked the intelligence-associated movements, like playing the violin, waving hands to someone, and dribbling a basketball. The authors used pre-, post-, and delayed-tests to measure conceptual understanding. Paired *t* test analyses on students' tests scores indicated that there were positive impacts of the gesture-based multimedia presentation on students' concept retention performances, immediately after the intervention and four weeks later than the intervention. Although it did not "clarify the comparative instructional effectiveness of embodied and nonembodied multimedia presentations" (p. 8), the study by Chang et al. (2013) provided initial evidence on the impact of Kinect-enabled, gesture-based presentation on students' cognitive learning outcomes. In the study, Kinect-based motors helped to obtain learners' attention and then metaphorized the target concepts to concretize the abstract knowledge, thus promoting information encoding and retention.

Previous empirical studies on learning and technology have shown that gestures prompt learning in a positive way. In an experimental study with 25 children aged around five, Valenzeno et al. (2003) investigated how teachers' gestures helped the transfer and concretization of the information relevant to the lesson content, and argued that an instructor's gestures related to the content knowledge "reinforced the verbal message" (p. 189), and facilitated comprehension of new concepts by linking the abstract knowledge "to the concrete, physical environment" (p. 200). Alibali and Nathan (2012) classified gestures that manifested cognition into three categories—pointing, representational, and metaphoric gestures. Pointing gestures help to attract learners' attention and make them concentrate on the selected part of learning materials. Representational and metaphoric gestures are those that concretize psychological perceptions and present motor-based concepts, among which representational ones are a direct translation or illustration of a concept while metaphoric ones are an extended representation of a more abstract concept. For example, a learner may interpret a gesture of playing the violin, like the one in Chang et al. (2013), as the concept of playing the violin, thus making the gesture representational. At the same time, s/he may also regard such a gesture as a concretized metaphor for the musical talent, thus making the gesture a metaphoric one that serves to concretize and represent an abstract psychological concept. Rumme et al. (2008) investigated pointing gestures in an English-as-a-second-language course with 97 Japanese students aged around twelve and thirteen, and compared the effects of pointing gestures with those of laser pointing. Results showed that an instructor's pointing gestures "play[ed] a central role in attracting, and keeping, a learner's attention" (p. 689), and pointing gestures could convey more affections related to the content knowledge than a laser pen could (Rumme et al. 2008).

Applying gesture-based learning in mathematics instruction has been prevalent in studies of the past decade (e.g., Alibali and Nathan 2012; Arzarello et al. 2009; Bautista et al. 2011; Edwards 2009; Goldin-Meadow et al. 2009; Reynolds and Reeve 2002; Shoval 2011). In those studies, gestures helped math learning in various forms. Edwards (2009), for example, studied the effects of gestures on math fraction learning by a group of 12 adult learners, who were prospective elementary school teachers. The author examined the "algorithms in the air" (p. 137) which were gestures representing the procedure of fraction calculation performed by the learners. The learners' gestures mapped the abstract mathematical ideas like the fractions and additions to movements, and evoked the symbolic expressions that represented math (Edwards 2009). These gestures, using Alibali and Nathan's (2012) taxonomy, can be interpreted as representational ones that encoded math calculation processes to lay their footprints in learners' memories. By examining how gestures expressed the abstract concepts and meanings, Edwards (2009) argued that gestures provided inputs to the conceptual knowledge, and was indeed part of the blends of mathematical ideas. In other words, motors prepared sources for psychological process and cognitive learning, and served as an initial part of the whole cognitive process. Goldin-Meadow et al. (2009) found that the grouping and pointing gestures attracted learners' attention toward numbers in mathematical equations and helped them process abstract math concepts. Through grouping and pointing gestures, learners selected the essential information related to math thinking while doing the calculation and hence managed to maintain an intense concentration. Yoon et al. (2011) studied mathematical gesture spaces that they referred to as "the multimodal use of gestures, speech, deictics, and so forth" (p. 389), by observing two experienced teachers during math instruction. The teachers posed their hands as a downhill slope and a metaphor for the abstract concept of a negative gradient. These aforementioned studies on gesture-based math teaching and learning showed that performing pointing, representational, and metaphoric gestures promoted active cognitive processing that led to improved learning outcomes.

Additional studies have examined gesture-based learning from varied academic perspectives (e.g., Allen 1995; Amorim et al. 2006; Bautista et al. 2011; Cook and Goldin-Meadow 2006; Glenberg and Kaschak 2002; Goldin-Meadow and Wagner 2005; Goldin-Meadow et al. 2009; Goldin-Meadow and Alibali 2013; Hsiao and Rashvand 2011; Kita and Davies 2009; Lee et al. 2012; Macedonia and Knosche 2011; Mizelle and Wheaton 2010; Sauter et al. 2012; So et al. 2012). A review of these studies indicates the following roles of gestures in cognition or information processing: First, gestures not only reflect a learner's thoughts, but also attract and inspire a learner's cognitive activities. Lee et al. (2012) applied the Microsoft Kinect to capture gestures like hand rising, waving, and pointing, to facilitate conversational language learning in a board-game-like environment. 39 non-English speaking college students participated in a 50-min English conversational course in the environment. The gestures were found to attract attention from learners and stimulate their thinking. Gestures also help a learner recall prior experience and knowledge to trigger the transfer between real-life knowledge and to-be-learned formal knowledge. In a study with 49 third and fourth grade children in a math lesson (Cook and Goldin-Meadow 2006), children in the experimental group received the instruction on a problem-solving strategy presented in gestures while the control group was not exposed to the gesture representation of the strategy. In the experimental condition, teachers produced gestures when they explained mathematic problems to the children. The children either spontaneously imitated the gestures from their teachers, or produced their own. Whether imitating or creating, the children who gestured during the instruction were found to be more successful in solving math problems during the instruction period than children who did not gesture. The study further reported that children who gestured during instruction were more likely to retain and generalize the knowledge gained than children who did not gesture. Gesture perception and production thus facilitated a learner's understanding of the relation between the problem in the real world and their own mental model of the problem (Cook and Goldin-Meadow 2006).

Second, learners can use gestures to encode and reinforce content knowledge. For the knowledge that is encoded through gestures, learners may access and apply it more frequently in memory. In an early study on foreign language learning utilizing gestures, Allen (1995) found that gestures accompanying the language learning process led to a better language recall and less loss since gestures provided an elaborated context for language learning and retention by facilitating the "binding," "mapping," and the "processes of internalization" (p. 527). Gesture production might encourage learners to form imagistic representations that could later be accessed (Cook and Goldin-Meadow 2006). Certain gestures also helped learners to strengthen the connections between concepts and emotions via externalized movements (Lee et al. 2012). Learners' physical actions in using a tool or operating an object may trigger the perceptual understanding and could be used to encode the representation of the tool or object, which then facilitates future cognitive activities of tool selection or control (Mizelle and Wheaton 2010). Motor activities are part of the encoding process. In a recent study, So et al. (2012) showed both adults (30 undergraduate students) and children (36 kids aged four to five) gesture-accompanying expressions of verbs, in comparison with non-gesture-accompanying expressions of verbs, and evaluated their mnemonic abilities under the two circumstances. Results revealed that people tend to remember the expressions of verbs with gestures better than non-gesture ones (So et al. 2012). Encoding motoric movements into memories help people better retain and comprehend the content knowledge. Shoval (2011) conducted an experimental study on the effect of mindful movements (i.e., body movements aiding academic learning) on academic achievements of 216 s and third grade students in learning angles. The experimental group learned the geometric content through movement-aided learning activities whereas the control group learned without. Statistically significant results showed that mindful movements improved learners' achievements to a greater extent than conventional learning, and there was a link between the number of times the learners perform those mindful movements and the improvement in the achievements (Shoval 2011). The body movements related to content knowledge in Shoval's study can be regarded as part of the cognition process, which is in agreement with the view that body is involved in cognitive processing (Mayer and DaPra 2012; Robbins and Aydele 2009). In other terms, the mindful movements encode the concepts with extended information to create the motorpsycho set and externalize learners' intrinsic thinking.

Third, gestures facilitate the transfer between the concrete or observable knowledge and abstract one by creating representations that link content knowledge with a learner's personal perception and psychological activity. Bautista et al. (2011) studied knowing, insight learning, and the integrity of kinetic movements. They performed a two-year longitudinal project on three elementary students in learning geometric objects and concepts with the help of kinetic movements. Based on the study findings, Bautista et al. (2011) argued that kinetic movements of human body are important for the emergence of abstract knowledge. In another study by Amorim et al. (2006), different body postures were used to concretize abstract ideas regarding mental spatial transformations. In the study by Chui (2011), the author examined archived conversational discourses in a university collection of spoken forms of Chinese (short oral narratives and daily face-to-face conversations) ranging from the year 1996 to 2010. By analyzing the data coded by two trained coders, Chui (2011) found that gestures conveyed people's metaphorical thoughts in their daily communication, and metaphorical gestures externalized what the speaker wanted to convey in mind. Similarly, Kita and Davies (2009) reported that gestures facilitated the conceptualization process of speaking after conducting a study on how 20 university students described geometric shapes. The gestures in Kita and Davies' study (2009) were arranged based on the complexity of the content knowledge, and designed to concretize and externalize abstract concepts. As illustrated by all those previous studies, motor activities deepen conceptual understanding and enhance the psychological achievement.

Motors and sense of presence

Another construct that is related to our discussion of motorpsycho approach is the sense of presence—the extent and likelihood that a learner feels being immersed into a virtual environment (Heeter 1992; Schloerb 1995). It is a learner’s psychological experience that s/he perceives regarding how much s/he is attached to a learning intervention. Body movements form an important part of the sense of presence by externalizing the presence with kinetic activities.

Offering learners the perception of being there has always been a major instructional design challenge for the technology-enhanced learning (TEL) environment Schuemie et al. (2001). Among TEL environments, the virtual reality (VR) has been a continuous trend. In VR-based learning, learners interact with pedagogical agents and learning objects within the virtual world. Hence the sense of presence becomes a salient feature of VR-based learning. Schuemie et al. (2001) concluded that involvement and immersion were “necessary for experiencing presence” (p. 185) in the virtual reality. Dede (2009) argued that the immersion presented by a VR-based learning scenario would enhance learning by providing learners with multiple perspectives in interacting with the content. Gestures and other motor activities in a VR setting will provide a haptic or embodied perspective to create the immersive, enhanced learning experience.

Researchers have examined the relationship between the sense of presence and performance in TEL environments through empirical studies and theoretical reviews (Aymerich-Franch 2010; Riva 2009; Slater et al. (1998). Riva (2009), by studying the link between actions and presence, suggested it was the sense of presence that bound the cognitive activities with actions. In a study (Slater et al. 1998) about body movements and the sense of presence, 20 learners were asked to wear head-mounted-display (HMD) devices to explore a virtual lab to accomplish some virtually-simulated fieldwork. Learners, with their HMD-devices on, performed different body movements in the scenario by turning their heads, bending down, or standing up in order to recognize some virtual plants. The study showed a significant result on the positive effect of body movements on the sense of presence. Slater et al. (1998) concluded that body movements during the virtual environment exploration helped to evoke the learners’ sense of presence which, in turn, induced similar reactions and emotions as those in a physical environment. In a recent study, (Joo et al. 2013) examined the sense of cognitive presence that reflected “a learner’s ability to understand the learning topic through learning activity and to generate and confirm her/his own knowledge” (p. 311). Results showed that the sense of cognitive presence had significant effect on the learning flow and the satisfaction of online learners (Joo et al. 2013).

In order to present the sense of presence, a learning environment should encompass interactive and thought-provoking activities in which gestures and other body movements may play active roles. In light of the discussion above, motors, via the construction of the sense of presence, enables a rich and active experience in a TEL setting to achieve the concretization and externalization of cognitive knowledge. Thus, the sense of presence ties motor and psycho-activities together in a positive way, by relaying the effect of motors onto the cognitive activities.

Motors reduce cognitive load and present multimodalities

Previous studies in learning cognition have shown that gesturing, either before or during instruction, may improve learning performance (e.g., Broaders et al. 2007; Goldin-Meadow et al. 2009; Ping and Goldin-Meadow 2010). An underlying reason, as those studies argued, is that gestures could reduce the cost associated with cognitive activities by releasing resources of working memory (Cook and Goldin-Meadow 2006). According to the information processing theory and the memory model (e.g., Atkinson and Shiffrin, 1968; Baddeley and Hitch, 1974; Driscoll 2005; Richey, 1986), working memory is limited, acting to retain chunks of transient information in mind. Cognitive activities, like reasoning and comprehension, are executed in working memory and can be enhanced via multimodal processing and interaction. Gestures may serve to supplement visual and auditory sensory modalities and off-load the cognitive assets or resources. Gesture production was associated with a reduction in cognitive load, and could directly change the online memory processes involved in storing new representations (Cook and Goldin-Meadow 2006). In an earlier piece of work, Donald (1991) suggested that people were often capable of more effectively performing cognitive tasks, memorizing and remembering for instance, through use of their bodies and parts of the surrounding environments so that to off-load the memory storage and to ease the nature of the cognitive processing. Another earlier study on how children counted objects while gesturing suggested that gestures might serve as an external storage or memory register of the working memory, which "could reduce resource demands by physically instantiating some of the contents of working memory" (Alibali and DiRusso 1999, p. 53).

Motors provide a learner with multiple ways or channels to conduct psychological activities, which helps the acquisition and retention of content knowledge. Valenzeno et al. (2003) claimed that "because gesture is a second communicative channel, a student has two 'opportunities' to comprehend a message that is expressed in both speech and gesture" (p. 200). The memory of action events is better maintained when the events are actually performed through movements than when they are only read or heard without moving (Ozcelik and Sengul 2012). Ozcelik and Sengul (2012) integrated learner gestures into a computer-based 3D environment to teach the concept of vectors in physics. In their exploratory study, they created a simulation for teaching 3-D vectors in physics by applying the Kinect. Participants drew the 3-D vectors by controlling the full body motion of the avatar in the virtual environment. Without wires or devices attached directly to the body, the participants found it enjoyable to freely control the avatar by moving their own bodies; they also perceived enhanced learning when using gestures while trying to understand a concept. The concept of vectors in physics was quite abstract and required spatial imagery. The motoric movements reduced the cost associated with information processing in the working memory. By representing the obscure concept via gestures that convey a semantic meaning, motors formed one more modality for learners to comprehend and memorize the concept, and lowered the cognitive load for a learner during information processing. Yu et al. (2009) studied the effect of motor actions related to visual perceptions, like grasping, touching, and moving, on how young children selected relevant information. The authors utilized a head-mounted camera and a third person camera to record and study how 15 toddlers selected and played with the toys in an experimental environment. Yu et al. (2009) found that manual activities (i.e., using hands to select objects of interest and to bring them close to the face) were substantial in helping toddlers select visuals (colors and shapes), and such activities might be "important ingredients in toddler intelligence and learning" (p. 149). For the toddler, the hand movements of bringing a selected toy closer to his/her face made the toy look larger, which would block the other toys and hence benefited object recognition by reducing cognitive distraction. The researchers further argued that the bodily actions were actually a "major factor" of the information selection and reduced the cognitive load for processing visual information, since bodily action provided a modality that was "perhaps cognitively 'cheaper'" (Yu et al. 2009, p. 149).

There are other empirical studies supporting the role of motors in reducing cognitive load and presenting multimodalities. Ezequiel and Robert (2004) found that learners gestured when they tried to describe objects that were difficult to encode verbally, and gestures helped both spatial memory and lexical retrieval. Broaders et al. (2007) found that gesturing was one modality to encode and process the ideas and knowledge when children were made to gesture while expressing implicit math knowledge. Cook et al. (2010) conducted a series of studies on how gestures helped with the process of information encoding for conceptual understanding and retention. They found that gesturing for encoding increased cognition recall, both instantly and after a period of time. They concluded that gestures might influence the way that information was stored and retrieved from the memory (Cook et al. 2010). Macedonia and Knosche (2011) showed that during language learning, learners had "better memory for words encoded with gestures" (p.196), and they tended to use the words encoded through gestures more frequently when making new sentences. The aforementioned findings demonstrated that gestures would act as another source of modality for learners to encode and retrieve words they learned.

Motors facilitate information communication

McNeill (1992) claimed that we typically gestured when we spoke to one another, and gesturing facilitated communication as well as language processing. The gestures of a speaker or instructor can "facilitate listeners' comprehension of speech" (Valenzeno et al. 2003, p. 188) and as a recent meta-analysis indicated, have a significant, moderate, and beneficial effect on communication (Hostetter 2011). Arzarello et al. (2009), after analyzing a mathematical teaching–learning process, claimed that gestures could serve as the semiotic bundle and communicative link to assist knowledge transmission. In their study, learners in a 11^{th} grade scientific class were asked to move their hands or fingers to mimic mathematical graphs and trace the key features on a graph while talking about these features. The study revealed that gesturing was part of the multimodal system for learning by serving as a communication means among students and instructors (Arzarello et al. 2009). Reynolds and Reeve (2002) observed and analyzed how two middle-school students discussed their math problems involving speed and time. They examined gestures of the students to judge what content knowledge the students concentrated on, whether and to what degree the students understood a certain topic. They concluded that gestures, besides maintaining joint-attention, also acted as a "cognitive amplifier" (p. 457) with which learners who were not familiar with the content knowledge could communicate about or demonstrate how much they understood (Reynolds and Reeve 2002). In Edwards (2009), pre-service elementary teachers gestured to "communicate about abstract or general mathematical objects or processes" (p. 137). They utilized such symbolic gestures to convey or transmit information regarding how to express and calculate fractions. As Edwards argued (2009), gestures should be part of the communication process.

Popular research arenas in gesture-based learning include language learning and learning-related communication (e.g., Bavelas et al. 1995; Church and Goldin-Meadow, 1986; Goldin-Meadow et al. 1993; Goldin-Meadow and Wagner 2005; Goldin-Meadow and Alibali 2013; Macedonia and Knosche 2011; Riseborough, 1982; Sauter et al. 2012).

Multiple previous studies have showed that gestures prompt language learning, as well as language communication when learning other content knowledge. Earlier studies on gestures and communications acknowledged gestures as a means to communicate, and identified the important roles of gestures in talking, speaking, and idea expression (Bavelas et al. 1995; Crowder and Newman 1993; DePaulo 1992; Feyereisen 1987; Kendon 1980; Riseborough 1982; Roth 1996). Particularly, gestures were found to assist learners to simulate, mimic, and extend the actions and perceptions demonstrated by all parties during communication. In an early study on people's hand gestures when retelling stories to each other, Bavelas et al. (1995) found that gestures in conversations illustrated the events, objects, actions, or ideas related to the topic. The authors further argued that gestures could deliver information, rehearse what other speakers had talked, trigger for responses from audience, and coordinate the sequence when multiple people were talking (Bavelas et al. 1995). Gestures could also help communicators to determine what and how much information is needed in each utterance (Kita and Davies 2009). In another comprehensive experimental study on language and gestures with 20 native English-speaking college students, Kita et al. (2007) examined how manner gestures and path gestures were associated with speeches. In this study, manner gestures represented the manner of a motion event (e.g., "jumped"), while path gestures represented the path or location information of the motion event (e.g., "down the hill"). The study found that speech and gesture production processes interface at the conceptual planning phase. Specifically, people utilized body gestures with linguistic representations and packaged gestures into units suitable for verbalization in an online manner rather than an offline mode in which people drew predefined conceptual schemas for idea expression. Gesture representations coordinate with linguistic ones while speech and communication are going on.

Based on the findings of the aforementioned studies, gestures are essential for information communication in two ways. One is to represent the concept, and the other is to communicate. Researchers in the field of embodied cognition argue that psychological activities are usually mediated and embedded in motor activities, which are externalizations of sensation and perception (e.g., Anderson 2003; Wilson 2002). There is empirical evidence showing that body movements help learning-related communication through assisting a learner's utterance and encouraging a listener to communicate (Alibali and Nathan 2012; Kelly et al. 2010; Kita and Davies 2009). Motor activities also embody the content knowledge, and situate it in learners' interactions with physical environments (Alibali and Nathan 2012; Birchfield and Johnson-Glenberg 2010; Borghi and Cimatti 2010; Davis and Markman 2012; Valenzeno et al. 2003). In summary, gestures or body movements convey information, assist representation or interpretation, and hence enhance learning and cognition.

Conclusion

Synthesizing the discussions in the previous two sections, we conclude that motor activities can facilitate and enhance both information processing and communication, which has a positive effect on psycho-activities during learning. Motors help to attract attention, stimulate thinking, encode information, concretize concepts, externalize ideas, lower cognitive costs, and offer more modalities or perspectives when learners process cognitive information. Motors also facilitate the communication of information, and interact with other modalities (like speeches) to strengthen psycho-activities. The motorpsycho approach reflects our discussion on the association between gestures and cognitions, especially the proactive role that motors play in psycho-activities.

It should be noted that by presenting motorpsycho, we do not mean that motors precede psycho-activities necessarily. Nor do we regard the motorpshycho approach as unidirectional. Rather, we acknowledge that the relationship between motors and psycho-activities are bidirectional. Gestures and cognition are interacting upon each other. In other words, motor and psycho affect and communicate with each other in a mutual way. For example, gesturing in language learning is typically considered the output or expression of intensions and treated as a system acquired after the cognitive acquisition of spoken language system and cultural norms (Gullberg 2006). At the same time, some social psychologists have proposed that bodily states, externalized through body movements and gestures, may influence social cognition (e.g., Barsalou et al. 2003; Barsalou 2008, 2010; Niedenthal et al. 2005). Even though cognitive knowledge and perceptions affect our bodily states, and may direct our motor activities, “bodily states are not simply effects of social cognition; they also cause it” (Barsalou 2008, p. 630). For instance, nodding one’s head normally produces and reflects positive affect in cognition, while pushing away with the arms normally leads to negative consequences (Barsalou 2008). When studying bodily states and social cognition, Niedenthal et al. (2005) argued that body movements helped the forming and recalling of cognitions. Meanwhile, attitudes, perception, and emotion influenced the motoric movements as well. Kelly et al. (2010) showed that gestures and speeches interacted mutually to represent content cognition and acted in a bidirectional way to convey information. The integration of gestures and speeches was “obligatory” (p.261) and people cannot help considering one while processing the other (Kelly et al. 2010). Gestures and speeches were naturally bundled for the mental cognition.

In this paper, we focus on discussing how motors facilitate the information processing and communication for psycho-activities. The 31 articles summarized in Table 1 have provided both theoretical underpinnings and empirical support for the previous discussions related to the salient roles of motors in cognitive learning. The arrangement of these articles highlights a variety of emerged roles of motor activities in facilitating information processing and communication. Specifically, motors may help to attract attention, encode information, concretize and externalize abstract ideas and concepts. Motors may reduce the cost and resources and hence serve as an extra modality for information processing. At the same time, motors facilitate information communication and act upon psycho-activities in an interactive way.

State of the Art

Our discussion on the relationship of gestures and learning cognition is stimulated by the emergence of the new body-sensory technology, such as the Microsoft Kinect. The Kinect may act as an affordable, advanced 3D body-sensory device to apply in the fields of entertainment, healthcare, and education. Some researchers have applied Kinect in designing instructions in special education. Chang et al. (2011) built a gesture recognition system with the help of Kinect to help individuals with cognitive impairments in their vocational tasks. Their experiment showed that Kinect-based intervention, “Kinempt” as they put, significantly improved the vocational performance. Recuay’s thesis (2011) presented a Kinect-based gaming platform to enhance physical and cognitive activity training for older adults. Some online Kinect-based educational communities, like KinectEducation Community, Microsoft Kinect in Education and Pil-Network, have been sharing opensource Kinect applications in education such as KinectMath, KineSis and KinectPaint. Some projects, like Kinection to Angles: Laws of Sines and Cosines, Kinect Olympics and We KINECTing History, can be openly found on the Internet and provide empirical evidence of learning effects. Some research labs in universities are also active in applying Kinect to varied experimental applications, such as creation of 3D shapes and learning of physical phenomena (e.g., Johnson-Glenberg 2012; Vinayak et al. 2013). Unfortunately, theoretical research is limited in these applications with regard to the underlying cognitive theories and learning approaches.

Technically, learning solutions in the applications utilizing Kinect belong to two categories. One is digital puppetry, and the other is interware-based. In digital puppetry, a learner controls an application directly through body gestures. Kinect captures a learner's physical movements and reflects them instantly and directly in the application. Typical examples are those Xbox body-controlling games related to education, and some on-going university research projects that make applications directly controllable by users' body gestures (Held et al. 2012; Leite and Orvalho 2011). In interware-based applications, as the name suggests, an installed interware interprets a user's gesture and matches them to different key pressings on the keyboard or different clicks of the mouse. These key pressings and mouse clicks may control the active applications on the desktop (Windows OS for example). A user or facilitator may define the matches between gestures (e.g., raising the arms, jumping a certain height, walking a short distance) and keys or mouse input within the interware. A learner can then control and indirectly interact with the active desktop applications using those designated gestures. A typical example of such an interware is the Flexible Action and Articulated Skeleton Toolkit, FAAST as they put, developed by a group of researchers in the University of Southern California (Suma et al. 2011; Suma et al. 2013).

An existing example that tries to integrate Kinect into learning is Jumpido (Jumpido OOD 2013), a mathematical learning platform for students aged from 6 to 12, developed by a Bulgarian start-up company. It is newly released in May 2013 and comprises a series of math games in which gameplay is performed via Kinect-based motor activities. For example, numerical calculation problems in a game are presented as fruits on tree branches while the solutions/answers are presented as the baskets at the bottom of the tree. The major game action is to grab the fruits (math equations) on the tree and put them into proper baskets (numerical answers). Students' limb movements are captured by Kinect to deliver the game action. Picking up fruits with actual limb movements, in comparison with the mouse-driven drag-and-drop, creates a stronger sense of presence or immersion, and hence will potentially motivate students to continue game-based math practices. The Kinect-interfaced gameplay, to certain degree, may involve students in both mental and physical interactions with the math content objects (e.g., equations and numbers). It also helps students to externalize their mathematical thinking by probing them to communicate their mental calculation processes with their teacher and peers, especially when they play together and disagree on the bucket choice. It should be noted that the game mechanics in Jumpido still lacks an intrinsic or semantic association between motors and mathematical thinking. The required motors have not actively represented math concepts or facilitated the organization or mapping of the mental calculation process, hence not helpful for information concretization or encoding. Another example that better demonstrates the usage of Kinect-integrated motor activities (or body movements) to actively encode and represent information is GEARS, an embodied learning game designed and developed by Johnson-Glenberg (2012) and her colleagues. In this game, the body movement of spinning arms matches structurally with the content to be learned—the science mechanism of mechanical advantage (represented by the diameter of the input gear, the speed and direction of gear-spinning, and the motion of the output gear). During game play, the player extend and spin the right arm directly in front of the body, with the right shoulder becoming the pivot point and tight circles around the shoulder joint making smaller gears. The player needs to maneuver the game object (an input gear) by mapping the circle and speed of the arm spinning to the diameter and speed of the gear, thus developing an embodied simulation and representation of the mechanism to be learned.

Discussion and implication

Body sensory technologies like the Kinect should provide new avenues to monitoring learners' body movements and gestures, and enable learners to interact with instructional interventions via motors or haptic customs. It is necessary to examine the theoretical underpinnings for the design and implementation of a Kinect-integrated, gesture-based learning environment. For its novelty, it is not surprising to find only preliminary studies directly related to body-sensory-technology-based learning. Consequently, we have reviewed and analyzed the gesture-based learning studies whose designs may be extended with the help of Kinect and other body sensory technologies. In our discussion, we propose a concept framework that was distilled from the prior theoretical and empirical research—the motorpsycho learning approach. We project that motors facilitate information processing and communication so as to enhance psychological activities in learning, as is illustrated in the following Fig. 1.

From the perspective of embodied cognition, cognitive processes are deeply rooted in the body's interactions with the world (Anderson 2003; Shapiro 2011; Wilson 2002). Researchers of embodied cognition define humans as essentially "acting beings" (Anderson 2003, p. 91) or "embodied agents", and argue that "our powers of advanced cognition vitally depend on a substrate of abilities for moving around in and coping with the world" (Anderson 2003, p. 126). Wilson (2002) stated that there was a growing idea that "the mind must be understood in the context of its relationship to a physical body that interacts with the world" (p. 625). Although it sounds a little radical, the concept that the body shaped the mind does have sensible support in the embodied cognition community. And what is more important, it shows the close relationship between the body and mind. Wilson and Foglia (2011) categorized the functionalities of the body on cognition into three types—constraint, distributor, and regulator. The body assists to constrain the extent and the nature of cognition, to distribute the psychological resources in cognition, and to regulate the settings of cognition. With the presence of body sensory technologies like the Kinect, well-designed instructional interventions will put body gestures and a learner's real-time interaction through a kinesthetic interface on the center of stage. A learning environment can be carefully designed into a console where body movements, through the body sensory technology, control the course of content learning. The body facilitates in real time the processing of the mental activities in response to the alternating environments. It may also help to convert the physical patterns into cognition, and externalize cognitive activities into physical ones. The body movements "regulate cognitive activity over space and time, ensuring that cognition and action are tightly coordinated" (Wilson and Foglia 2011), and hence enhance the concordance between motor- and psycho-activities.

In this article, we deliberately avoid diving too much into embodied cognition due to some controversy in the research community. As Barsalou (2008) commented, the embodied cognition community seemed to "problematically" insist on believing that physical movements and "bodily states are necessary for cognition and that these

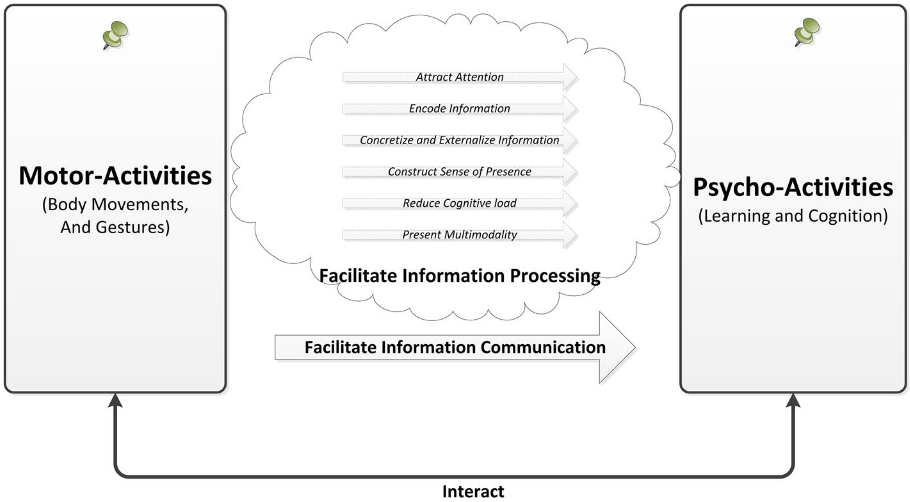

Fig. 1 The motorpsycho learning approach. *Note* The single *arrows* in this figure do not necessarily suggests any directions. They reflect the supportive roles motor play on psycho-activities

researchers focus exclusively on bodily states in their investigations" (p. 619). Yet, there are cognitive activities which involve no bodily movements and are grounded in aspects other than gestures (Barsalou 2008, 2010). In our article, we do not mean to compare 'right' from 'wrong' (there is no right or wrong regarding this topic in our view). However, we concentrate on cognitive learning that involve motor activities, like gesture-based mathematics and language learning, in which body movements are part of the learning activities, and serve to facilitate information processing and communication. We propose our motorpsycho point of view to prompt related research. It is not our attempt to show that all psychological activities involve motor activities necessarily. Nevertheless, we delineate the important roles that motors play on psychological activities, especially in learning cognition. We aim to address the fundamental affordances of the body sensory technology for the development of conceptual understanding and knowledge acquisition in gesture-based learning.

The motorpsycho approach can serve as a design and evaluation framework for the future research on the educational applications involving Kinect or other body sensory technologies. A sensory-technology-integrated learning application should align its salient features or functions with one or multiple aforementioned roles of motor activities in facilitating psycho activities. The motorpsycho framework can also complement other active learning approaches, such as the constructionism-rooted, learning-through-design approach (Harel and Papert 1991) or the computer-supported collaborative learning process (Stahl et al. 2006), to guide the design of an engaging and active learning environment. For example, a recent project on the design of a virtual-reality-based, constructionism-based learning application indicated that even though virtual 3D-object maneuvering and artifact construction can promote math conceptual learning, the mouse- and keyboard-based gameplay has negatively influenced the sense of presence and math learning experience (Qiang and Ke 2013; Xu et al. 2013). Integrating a Kinect-enabled haptic interface should make the VR-based, learning-through-design process a lot more immersive. Hand movements involved in composing and decomposing artifacts can potentially help virtual players to encode, represent, and extract the underlying computational and mathematical thinking.

Limitations and future research

In this conceptual article, we propose a motorpsycho approach in gesture-based learning in which the innovative body sensory technologies may play an active role. The searching of articles was limited by the novelty of the topic. Few articles are directly related to gesture-based learning with Kinect involved. For the few that exists, some of them are exploratory studies that may suffer from external validity issues themselves. When enlarging our sight of article searching, we concentrate on journal articles related to gestures and learning whose designs could be replicated and extended with the help of body sensory technologies. The articles included are less than exhaustive in that we aim at articles that will shed light on the exploration and discussion of the motorpsycho approach.

Although the conceptual framework of motorpsycho is in need of empirical investigation and theoretical investigations, the motorpsycho framework could guide the future research of gesture-based learning. Since the body sensory technology like Kinect may offer great and affordable possibilities to involve body gestures and movements in the interactions between learners and instructional interventions, we call for more empirical studies that will practice and examine the motorpsycho learning approach. During the writing of this article, Microsoft has announced its new Xbox One® console with an updated version of the Kinect sensor. And a more precise hand gesture capturing tool, the LeapMotion®, has also come into the market. Briefly, we speculate that the future research roadmap may be on three tracks: First, design research studies similar to those that have been carried out in existing studies but with the inclusion of body sensory technologies; second, research on those commercial gesture-based games that can be adopted for educational use; third, design research studies which are tailored to the educational applications of body sensory technologies. We also believe that it is profitable to develop an interdisciplinary research community, with members from learning technology, computer science, and engineering, for the design and evaluation of learning applications enhanced with body sensory technologies.

In summary, we hope that our discussion of a motorpsycho learning approach will help to support and expand the promising research in body-movement- or gesture-based learning. A future study can be an empirical and design-based investigation on the implementation and effectiveness of a motorpsycho learning environment.

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