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Exploring possibilities for synergizing embodied, embedded and extended cognition: Implications to STEM Education

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Abstract. Cognitive studies have resulted in great improvements in deeper learning. This paper explores groundings for synergizing embodied, embedded and extended cognition by looking at first, theoretical foundations and issues of interrelated disciplines, and second, ponders what the difference would be if the centrality of design shifts between a creativity/knowledge-building epistemology and a resource-based/optimization epistemology based on the same design factors. Third, we consider what the implications to STEM Education would be.

1. Introduction

Learning and retention are two key difficulties that many students face. Hence, cognition has increasingly become the focus of research related to Newell and Simon’s (1972) problem-solving, with the intention of investigating mechanisms, which can enhance or hinder learning and retention. In response to these two key difficulties, Mayer (2009) in his theory of multimedia learning has highlighted 12 principles for the design of multimedia learning environments/simulations. These principles apply to computer-based interactions, while taking into consideration limited cognitive processing capacities.

More recently, the 2016 International Conference on the Learning Sciences and respective workshops have addressed these issues in relation to deeper learning. Many findings point out the importance of viewing effective design holistically, complementing authentic whole task experiences with discovery-based design, and analysing learning in terms of not only complex cognitive processes, but also a holistic design. These findings also highlight how deep learning in inquiry and problem-solving contexts can be empowered and evaluated, the challenges experienced (e.g., methodological complexity, extended research process, need for domain knowledge, and commitment to advancing both theory and practice) and useful strategies so as to improve learning outcomes.

The above deals with digital simulated learning environments contained in the tool/learning environment. A phenomenological perspective promotes that concepts and schema are formed and revised over time triggered by externally-influenced factors or self-organization. Such dynamical view of systems and self-organization within such systems as is typical of systems engineering, point towards modularity and how enactive agency can help to refine propositional encoding as well as action schemas towards the formulation of generalizations. Synergizing embedded, extended and embodied cognition within the situated cognition framework may thus improve interaction/learning outcomes. The three different types of cognition are defined in Table 1 below.

Table 1. Definitions of three types of cognition

Type of cognition	Definition	Authors
Embodied	concerned with specific significant causal or physically constitutive roles of the body on cognition	Clark (2008) and Shapiro (2011)

Embedded	cognition as off-loading cognitive processing onto the physical, social and cultural environment – framed by situated cognition, where learning or behaviour as a result of interaction with a dynamic ecological environment	Donald (1991)
Extended	features of an agent's physical, social, and cultural environment as possibilities not only for in-situ processing but also for distributed cognitive processing	Wilson (2004)

All three definitions highlight attempts to simplify or extend the nature of cognitive processing. Cognitive processing leads us to the concept of affordances. For example, for embedded cognition, affordances are encapsulated and yet perceived (with or without relation to the user's environment). The use of post-it notes however, simplifies. Putting post-it notes on the body to label or remind exemplify embodied cognition. Extending post-it notes to social media distributes/extends cognition.

2. Objectives

Our objectives are to investigate the following research questions:

a) Can we synergize these forms of cognition? If yes, how?
b) Is it possible to apply a creativity/knowledge-building epistemology and a resource-based/optimization epistemology to the same design factors? What would the research model look like?
c) How would STEM Education benefit from these findings?
d) This paper next presents related theoretical groundings and the related issues raised, how findings are used to design two healthcare systems and two other activities for seniors and conclude with future work.

3. Related work and discussion

Emphasis on recognition of features of an agent's physical, social, and cultural environment aids propositional encoding through modality-specific representations and manipulations. Since people construct concepts differently in different contexts, three main factors may influence conceptualization:

a) The role of visual processing as highlighted by Gibson (1979);
b) Hutchins's (1995) view that constraining, distributing or regulating cognition would either enhance or hinder sensorial inputs and processing;
c) Solomon and Barsalou's (2001) study that the pattern of interaction may influence distributed/extended cognition.

Aside from these technical concerns, from a more human-centered/systemic/phenomenological perspective, Keller's (2010) Attention, Relevance, Confidence and Satisfaction (ARCS) motivation theory links visual processing to include needs and experiences. Designing the interaction to scaffold/afford such modalities and property verification thus play pivotal roles. This is especially in view of emergent and self-organizing schematic developments. This leads us to a knowledge-building-based perspective.

4. Knowledge-building vs. resource-based research model

From a Learning Sciences' knowledge building/creativity epistemology and approach, Lee, Kolodner and Goel's (2011) special issue grounded on Problem-based Learning-Learning-by-Design (Kolodner, Camp, Crismond, Fasse, Gray, Holbrook, Puntambekar, & Ryan, 2003) consider the following questions:

- How, precisely, can design and creative capabilities be promoted in formal and informal education?
- What are the principles for generating activities and curricula that promote creative design?
- What scaffolding do learners need to become more creative and to learn to design?
- How can responsibility for scaffolding be distributed between teacher, peers, and computing technologies?

To answer these questions, we find that the Learning Sciences, the IEEE, design thinking and computational thinking share common foundations in ideation and computational representations, simulations and manipulations. Being interdisciplinary, these three disciplines provide synergistic and well-grounded frameworks and channels for further investigating how to address changing design challenges such as Duderstadt's (2007) Millenium Grand Challenges. In line with the three interdisciplinary frameworks, subsequent works in the Creative Industries (Lee & Wong, 2015), Software Design and Testing (Lee, Wong & Lau, 2015), e-Commerce (Lee & Wong, 2016), Information Systems Analysis and Design (Lee & Wong, 2017) have strived to address these questions and investigated design scaffolds to increase cognitive access, learning transfer and creative outcomes. The progression is illustrated in Figure 1.

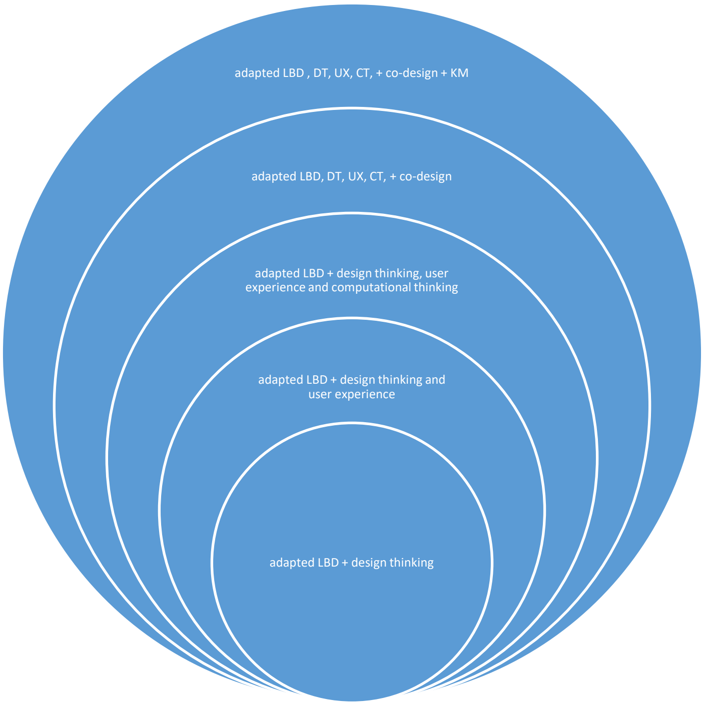

Figure 1. Progression of studies

First contextualized within the Cognitive Modelling "Laboratory" (Lee, 2007), these works extend the intelligent tutoring systems framework towards achieving user experience, sustainability and entrepreneurship in line with design thinking. Lee and Lee's (2015) study on design factors to inculcate creativity among students undertaking the course Robotics and Automation however, targets only sustainability and entrepreneurship, minus user experience, as the design would involve robots and the robot's environment and processes within that ecosystem rather than humans'.

Due to the very close relation between robotics and cognition in Systems, Man and Cybernetics (SMC), the focus is on emergence in self-organization. The methodology across these studies is similar to the SOM-PCA described in Lee (2007), whereby after self-organization, significant factors are identified. This methodology is one of the unsupervised learning data mining techniques, with emergent iterative processes and outcomes. In the Learning Sciences, this leads to the development of epistemic agency, necessary in view of lifelong learning, another tenet/aspiration of the IEEE.

What's most interesting is that whether in the creative industries or the Sciences, creativity design factors match Carnegie Mellon University's rubrics for Information Systems projects as foundational. These rubrics attest to the efficacy of design and computational thinking. Thereafter, the respective discipline determines the foci and degree of emphasis or centrality of design (user experience/sustainability/ entrepreneurship).

Figure 2 shows the most recent model from the evolution of our research model. The same epistemology has been applied throughout the series of studies. Hence, Figure 2 serves as a reference model. Components can be used as deemed fit, to suit different contexts.

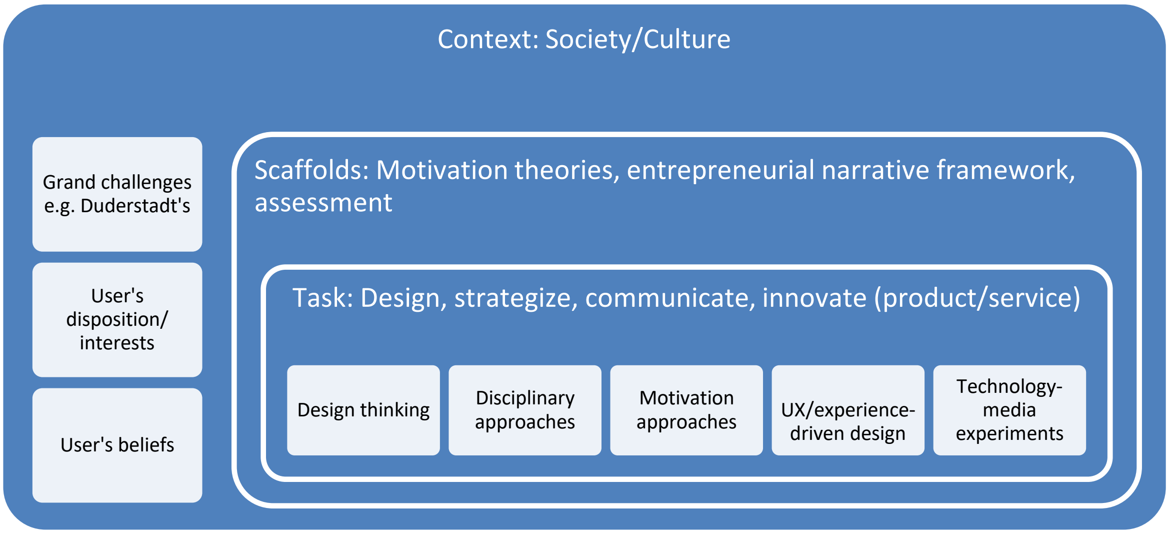

Figure 2. Research model for social-cognitive-affective learning and engagement based on 2013-2017 research

The studies thus far have focused on knowledge-building. The question is, can the same design factors be used with different epistemologies, i.e., creativity/knowledge-based and resource/optimization based? Figure 3 presents the possible changes in the research model, reflecting not only changes in the centrality of design but also the design itself. In Figure 3, resource-based views will mostly arise from project management (PM) concerns such as scope, time, cost and quality or the reuse of resources. Hence, Figure 3 has to be viewed and used cautiously based on objectives, epistemology and discipline.

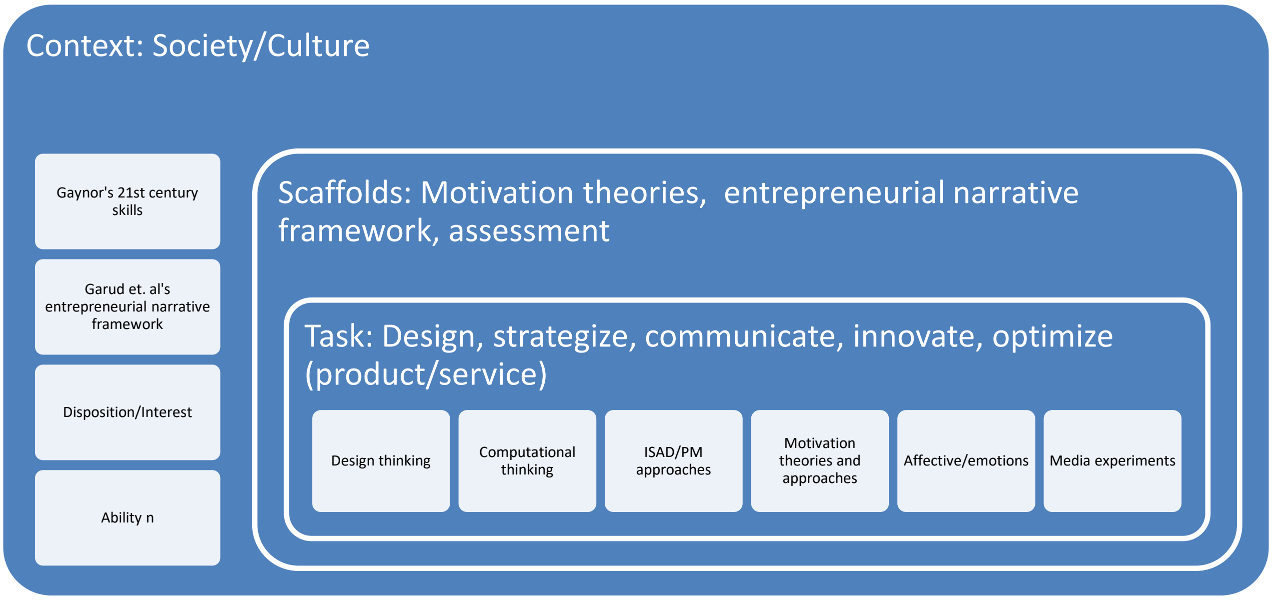

Figure 3. Changes in centrality of design highlighting differences between a three-layered creativity/interactional knowledge-based/phenomenological model (Figure 1) to a three-layered resource-based model (this figure)

However, if cognition, neuroscience, psychology and robotics are put together as is possible by synergizing these three kinds of cognition, what will be the outcome, i.e., robotic humans or creative robots? The latter is acceptable with great benefits such as domestic help and intelligent tutoring/companion. However, a new trend is brain-machine interfacing (BMI). Furthermore, the precision by which cognitive processes can be understood means that it can be inferred somewhat to normal humans and can be tweaked through psychological experiments. What if the noble initiatives of systems engineering in brain-machine interfacing (BMI) are abused by some to become brain-machine hacking (BMH)? What if people (adults and kids) just want to have fun and/or to show their prowess? What if this fun and prowess become addictive? These concerns take on greater dimensions in view of trends towards Big Data and Internet of Things (IoT). Examples of BMI and BMH are shown in Figures 4a and 4b.

We are beginners when it comes to cognition, psychology and neuroscience. Hence, perhaps the above is an over-simplification of issues and/or overamplification of issues in the field. Wilson and Fogliaa (2000) present the full spectrum of issues. The above discussion is aimed at highlighting the wide range of possibilities for embodied, embedded and extended cognition in diverse fields. Concerns aside, there is much good that can be generated through technology and interdisciplinary research, Big Data and IoT – to improve quality of life. The two research models are possible starting points from which we can synergize and mash to meet authentic design challenges, through media-based computational and design thinking.

Figures 4a and 4b. Examples of brain-machine interfacing hackathons (IEEE SMC, July 2017)

5. Examples

Interpretive affordances are more akin to sense-making, with regards to relational properties. The possibility for action exists regardless of how the user perceives the affordance. For example, a door knob's affordance exists even if the user is not going to turn the knob. This is akin to Gibson's (1997) affordance. Later definitions of affordances promote the socio-cultural influences on interpretation; involving the user's perception as part of the interactive equation.

We categorize affordances into two types: interpretive affordances and expressive affordances. The former's degree of complexity in terms of availability of context and level of details determine its outcomes. The latter can involve a double loop, reversing the sense-making and design challenge from the user to the designer, i.e., to help the user to interact in diverse manner based on specific objectives, the socio-cultural scenario and the user's personality, mood and logic. Both mediate action and both involve concerns such as the context, "universe of discourse" and the required cognitive processing of the afforded object but to different degrees.

Based on the research model in Figure 2, two activities and two examples of systems implemented have been investigated. They form possible ground for further extending to other forms of cognition in view of the above discussions Examples are presented in Figure 5a (JP, 2017) [not the author's], Figures 5b and 5c (Lee & Wong, 2017) and Figure 5d (Lee, Chan & Guy, 2017). The types of cognition they exemplify are varied.

Jigsaws require piecing together pieces based on a pre-conceived idea of the whole picture. This is an example of embedded cognition, but grounded in Gestalt psychology. For the craft in Figure 5b, expression involves embedded cognition as semiotics itself can be interpreted differently by different people. Similarly, for Figure 5c, there is embedded cognition as there is interpretation of actions that need to be carried out and how. For Figure 5d, there is extended cognition, as interpretation leads to movement and action such as sharing recipes, dancing along with the dance videos.

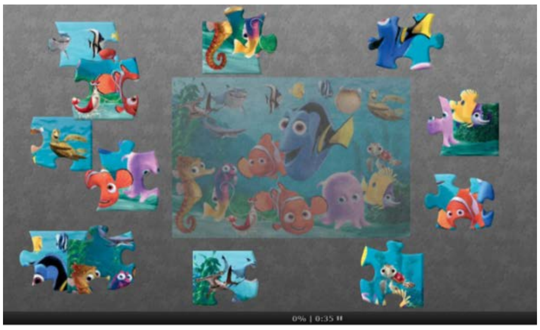

Figure 5a. Jigsaws (interpretive)

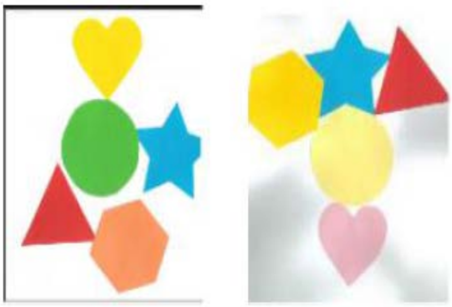

Figure 5b. Crafts (expressive)

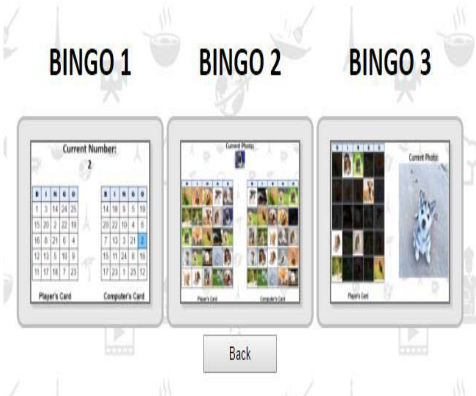

Figure 5c. Three variants of the bingo game (interpretive)

Figure 5d. MoveIt Dancing Page (expressive)

Figures 5d and 5e. Resource-based examples for pre-school (Introduction to Multimedia, UTAR, 2015)

Better examples with regards to the international digital maker movement carried out by the Malaysian Digital Economy Corporation (MDeC), includes games, animation and virtual reality development, as well as the non-hacking side of IEEE SMC robotics, i.e., the learning of Science through making/mashing. In all these, computational thinking serves to bridge the gap between computational theory and practice, providing room for imagination and creativity along with design thinking.

Some snapshots from the recent #mydigitalmaker Fair in Malaysia are shown in Figure 9. With the caption *Be a dreamer, be a maker*, these workshops are similar to the digital maker movements internationally and it is great to know that parents themselves are interested and marvel at what Science can do. They are the best Science motivators. Workshop registrations were full with many waiting in queue. The most wonderful aspect is these workshops are free to applicants who qualify. Nevertheless, there is a long way to go.

Figure 9. Future innovators

6. Implications to STEM Education

Never before have Science disciplines been 'challenged' as it is now due to the need to innovate/transform. Considering the diversity of disciplines, contextual dimensions and varied issues from different approaches or synergistic approaches, STEM Education needs to ground students in the Sciences more solidly than ever in order to build solid foundations. To remind us of our own humanity, STEAM and Liberal Arts/Education would provide holistic answers but how to integrate with Science and to what extent is the next question as disciplinary foundations must be primary. Ultimately, the market decides, but so does the respective discipline.

First, we need to recognize that the physical, social and cultural factors to be considered in diverse approaches such as a phenomenological or Industrial 4.0 contexts do highlight the variance in centrality of design suited to various contexts. Many in the Learning Sciences have chosen the middle path cautiously, acknowledging the benefits and precision of neuroscience to enhance the quality of life of those in need, downplaying emotions research while augmenting human learning capabilities. We agree and note that open-ended emergent environments complement formal learning in a fuzzy yet positive manner.

Second, in view of the latest trends in technological advancements aimed at meeting the diversity of human needs and augmenting positive experiences, a loose coupling between a resource-based/optimization approach and a knowledge-based approach may be advantageous if we are to explore possibilities for embodied, embedded and extended cognition. We further contend that the aim has to be in view of personhood (improving quality of life) in view of the original epistemology for our past studies, espoused by the Learning Sciences and the IEEE. In addition, we conjecture that the suitability of each model would depend on contextual needs, intrinsic leadership as well as communal beliefs, the availability of resources and capability maturity level of each context (in line with common Information Systems principles and concepts). Effects and implications will however, be different among different cultures.

These three types of cognition have broadened dimensions for investigating Lee, Kolodner and Goel's (2011) questions on developing creativity. Future work will be with a young target group who characteristically keep repeating certain actions. If we continue with this research, we will present our hypothesis why and how we propose to transfer these findings.

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References

Clark, A. (2008). *Supersizing the Mind: Embodiment, Action, and Cognitive Extension*, New York: Oxford University Press.

Duderstadt, J. J. (2008). Engineering for a Changing World: A Roadmap to the Future of Engineering Practice, Research, and Education, The Millennium Project, The University of Michigan.

Gibson, J.J. (1979). *The Ecological Approach to Visual Perception*, Boston: Houghton Mifflin.

Hutchins, E. (1995). *Cognition in the Wild*, Cambridge, MA: MIT Press.

Jigsaw Planet. Available: https://www.jigsawplanet.com/ [Accessed: March 2015].

Keller, J. M. (2010). ARCS Motivation Model.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntambekar, S. and Ryan. M. (2003). Problem-Based Learning Meets Case-Based Reasoning in the Middle-School Science Classroom: Putting Learning by Design™ Into Practice. The Journal of the Learning Sciences, 12(4), 495–547, 2003, Lawrence Erlbaum Associates, Inc.

Lee, C. S. (2007). Diagnostic, predictive and compositional modeling with data mining in integrated learning environments. Computers & Education, 49(3), 562-580.

Lee, C. S. and Wong, K. D. (2015). Discovering an Ontological Affective-Socio-Cognitive Co-Design Model: Towards a Symbiotic Context-Aware Recommender, International Conference on Cognition and Exploratory Learning in the Digital Age, October 24-26, 2015, Ireland.

Lee, C. S., Wong, K. D. and Lau, S. B. Y. (2015). Scaffolds and design factors to increase creative outcomes in teaching Software Design and Testing, IEEE International Conference on Industrial Engineering and Engineering Management, December 9-12, 2015, Singapore.

Lee, C. S. and Lee, J. V. (2015). Investigating design factors/scaffolds to improve knowledge building and creative outcomes in Robotics and Automation. Technical report. Universiti Tunku Abdul Rahman Research Grant.

Lee, C. S. and Wong, K. D. (2016). E-commerce Web design engineering: Towards discovery of innovational opportunities, IEEE International Conference on Advanced Learning Technologies, July 25-28, 2016, Austin, Texas.

Lee, C. S. and Wong, K. D. (2017). An entrepreneurial narrative media-model framework for knowledge building and open co-design, IEEE SAI Computing, July 18-20, 2017, London, UK.

Lee, C. S. and Wong, K. D. (2017). Developing Community-based Engagement in Smart Cities: A Design-computational Thinking Approach, IEEE International Conference on Industrial Engineering and Engineering Management, December 10-13, 2017, Singapore.

Lee, C. S., Chan, W. L. and Guy, S. Y. (2017). Socially-enhanced Variants of Mobile Bingo Game: Towards Personalized Cognitive and Social Engagement among Seniors. International Conference on Soft Computing, Intelligent System and Information Technology. Bali, Indonesia, September 26-29, 2017.

Mayer, R. E. 2009. Multimedia Learning. Cambridge University Press.

Newell, A., and Simon, H.A. (1972). *Human problem solving*, Englewood Cliffs, NJ: Prentice-Hall.

Shapiro, L., 2011, *Embodied Cognition*. New York: Routledge.

Solomon, K.O., and Barsalou, L.W. (2001). Representing properties locally. *Cognitive Psychology*, 43: 129–169.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin and Review*, 9: 625–636.

Wilson, R. A. and Fogliaa, L. (2015). Embodied cognition. Stanford Encyclopaedia of Philosophy.