Title

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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 36(36)

ISSN

1069-7977

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Publication Date

2014

Peer reviewed

The Implications of Embodiment for Mathematics and Computing Education

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Keywords: Embodied cognition; mathematics; computing; education; learning design

Goal and Scope

This symposium is a venue for discussing the implications of embodied cognition research for mathematics and computing education. Our goal is to bring five themes together that we think are complementary in understanding what embodiment holds for math and computing education: (1) Empirical studies: Behavioral, neuroscience, and neuropsychological work on sensorimotor groundings of higher-cognition, (2) The impact of perspectives in embodied cognition on a philosophy of mathematics, (3) Embodied interaction & ubiquitous computing: Recent trends in human-computer interaction that propose physical and social embedding in the world as basis for interaction, (4) Embodied interaction and the arts: Trends in aesthetic computing that result in crafting artistically-derived notations and representations of mathematics and computing, and (5) Embodied learning: Wide range of approaches in education that view bodily involvement as a crucial aspect of the learning process. By accounting for work in these five areas we will bridge empirical and philosophical studies on embodiment with learning and communication design work. Our goal is to present a comprehensive story of embodiment of mathematical cognition by covering and relating multiple levels, from sensorimotor neural circuits that support mathematical cognition to technological external representations that facilitate learning of mathematical concepts and ideas.

Theoretical Framework

Embodied cognition is a theoretical view of cognitive processes, arguing that these processes are best understood when they are seen as grounded in the body's interaction with the world. It represents a loosely connected set of theories grounded in multiple disciplines with the common notion of a bodily grounding for cognition. Kiverstein and Clark's (2009) classification of embodied approaches distinguishes those that regard embodiment as a component of cognition (extended functionalism) from those for which it is a central tenet (enactivism). We present a perspective that falls into the latter category. Our approach is also informed by Barsalou's (2008) grounded cognition theory that characterizes cognition as a simulation of perceptual, motor and introspective states. Central to our thinking is that if cognition is embodied then 1) we should explore ways of creating human-information interfaces that exemplify high degrees of embodied cognition, and 2) we should leverage disciplines, which tend toward increased levels and densities of human-information interaction, such as art and design. This approach could provide a more holistic view of aesthetics, which merges the apparently disembodied definition of aesthetic in mathematics (e.g. beautiful proof) with the broader definitions within the arts and humanities (e.g., sensory-based beauty).

Rationale

The meaning of embodiment for education, and the implications of embodied cognition for learning design, have become key issues in recent educational discourse. Among these discussions mathematics learning constitutes a special place since mathematics is often perceived as the most abstract and "disembodied" domain of human thought. Considerable research has been done on bodily groundings of mathematical cognition. However, the implications of these studies for mathematics, computing education, and learning design have not been widely discussed.

In parallel to the work on the bodily groundings of cognition, theoretical and technological innovations in human-computer interaction allow the development of learning technologies that provide learners with dynamic, interactive, and embodied experiences. Recent advances in a wide range of computational platforms afford the development of embodied and ubiquitous gaming, mobile, and sensing technologies that can better take advantage of natural human abilities and tendencies for interaction. Design aesthetics dominate the human-information interfaces in these technologies.

There is both the need for theoretical discussions on what embodiment means for mathematics learning and assessment, as well as how embodied technologies and computational environments can help us realize an embodied learning design vision.

Embodied Languages and Notations

Paul Fishwick

As evidence for embodied cognition grows, we ask what effects this growth will have on the understanding of the foundations of computer and information science? We argue that embodied cognition as both a subject of empirical study and philosophy will fundamentally alter our way of thinking about computer science. For example, an embodied perspective on the computing concepts of sequence and iteration is explained through the use of the body, mechanically. The mechanical approach takes us back into the ancient history of computing when information was encoded, decoded, and processed through analog means. The methods of analog computing, however, are largely missing from computing education. This situation leads to reintroducing analog machines, often using new technologies such as 3D fabrication and augmented or virtual reality. We will present a history of analog computing within the context of embodied cognition and its future implications for improving computing education.

Embodied Learning and Design

Dragan Trninic

How does embodied activity become symbolically articulated? How, if at all, should instructors foster the embodiment of new notions, and how should they guide students to articulate these notions in standard forms? To approach these questions, Dragan Trninic has been involved in pedagogical design for the content of proportional reasoning. Within novel learning environments, students first embody the target concept of proportion as a coordinated bi-manual performance and only later, under tutorial guidance, signify this performance in the mathematical semiotic system using a set of instruments interpolated into the problem space. Findings suggest that in the realm of elementary mathematics, conceptual development is much closer to motor skill development than previously supposed. This holds direct implications for reform math education movement, where conceptual understanding is emphasized often at the expense of procedural fluency.

Mathematical Cognition and Perception

David Landy

Mathematical tools and formalisms encapsulate experience in the physical world, and allow for conceptual abstractions. At the same time, formalisms are themselves physical systems, which are engaged via perceptual and motor processes. As computational devices become more ubiquitous, symbol systems are more and more dynamic and interactive. How can our understanding of embodied approaches to mathematical formalisms and diagrams inform the development of these systems? David Landy will trace a project starting from basic cognitive research through the construction of a pedagogical design project applying an embodied perspective to the design of an interface for symbolic manipulation. David will present the results of two experiments demonstrating that the use of such a system in typical classrooms leads to more flexible and more accurate symbol use.

Embodied Mathematics & Philosophy

Joselle Kehoe

Mathematics has been the subject of experimental studies in cognitive science that explore the sensory grounding of number and magnitude. But mathematics also provides conceptual schemes that can manage our comprehension of complex integrated neural activity, like Giulio Tononi's qualia space. Visual processes, like stereopsis, may be said to be mathematical in character, and the brain is often described as performing computations on sensory data as it constructs the elements of our experience. Mathematician Yehuda Rav has argued that mathematics grows on the scaffolding of cognitive mechanisms that have become genetically fixed with human adaptation. Joselle Kehoe will present a philosophy of mathematics informed by the significance of selected studies in cognitive science and selected moments in the history of mathematics. It will be considered in the light of structural coupling – the embodiment concept of enaction introduced by Varela, Thompson and Rosch.

Educational Neuroscience of Mathematical Cognition

Firat Soylu

One of the main claims of the embodiment thesis is that cognitive processes are grounded in the sensorimotor system. From an evolutionary perspective, new cognitive skills are acquired by redeployment of existing neural regions that originally participate in sensorimotor tasks. Understanding neural correlates of mathematical cognition requires the study of bodily processes and the sensorimotor circuitry that underlie number processing. In this talk Firat Soylu will review research on the neural correlates of number processing, how sensorimotor neural resources selectively participate in various number processing tasks and discuss implications of neuroscience findings for learning design and educational practice.

To exemplify the body and mathematical cognition relation Firat will focus on how finger related sensorimotor circuitry participate in mathematical cognition, review what we know on the neuropsychological, cultural and developmental aspects of the finger & number relation, and present findings from behavioral and fMRI dual-task experiments testing hypotheses on how the finger sensorimotor circuitry participate in number processing with adult participants. Firat will also discuss the educational implications of findings on the finger & number relation, and how new technologies can be used to consolidate finger-based, symbolic, phonetic, and perceptual representations of numbers during early development.

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