Learning through modeling and simulation: a grounded cognition perspective

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Reason for research

- Student
- Simulation
- System
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Learning by simulation-building

System → Conceptual model → Computational model → Simulation program → Mental model(s)
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Learning by using simulation

Simulation program

Computational model

Conceptual model

System

Mental model(s)
Mental models

The mind develops “small-scale models of reality” on the basis of experience and uses these models to think, to predict future events, and to provide explanations (Kenneth Craik, 1943)
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Mental models: the reasoning-based approach

Structural analogues of the world. The structural relations between their elements correspond to the perceptible relations between the elements of the corresponding real-world objects (Johnson-Laird, 1983)
Mental models: the knowledge-based approach

Knowledge structures people use to understand specific domains. People tend to rely on “naive theories” to describe and explain them. (Gentner and Stevens, 1983)
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Model-Based Learning and Teaching

- Internal models
  - Mental models

- External models
  - Physical models
    - Drawings
    - Equations
    - Symbols
    - Verbal descriptions
    - Gestures
    - Computational models
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Learning as a progression of mental models

Initial model

Intermediate models

Target model

Mental model(s)
Simulation-based learning

Preconceptions → Intermediate models → Target model

Mental model(s)
From mental models to mental simulation

“it should be possible for people to ‘run’ their models mentally” (Norman, 1983)

“mental models often permit mental simulation: the sense of being able to run a mental model internally” (Gentner, 2002)
“It would be possible to take the output of the mental model and replace the stimulus input from the world with input from our model of the world. In this case, we could expect that we could ‘run a mental simulation’ and imagine the events that would take place in the world when we performed a particular action.” (Rumelhart et al, 1986)
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An analogy

Mental model → Mental simulation → ? → Computational model → Computer simulation
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Mental simulation in Theory of Mind (ToM)

Human beings use their mental resources to simulate the psychological causes of other people’s behavior (Goldman, 2006)
Mental simulation in Cognitive Psychology

The re-enactment of perceptual, motor, and introspective states acquired during experience with the world, body, and mind (Barsalou, 2008)
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Mental simulation in cognitive linguistics

A comprehension mechanism for figurative language and conceptual metaphors (Gibbs, 2006)

YOUR RELATIONSHIP WAS MOVING ALONG IN THE RIGHT DIRECTION
Mental simulation in cognitive linguistics

Phrase

Your relationship was moving along in the good direction

Conceptual metaphor

LOVE IS A JOURNEY

Image-schema

SOURCE-PATH-GOAL

Embodied simulation

Kinesthetic experience of travelling along a path toward a goal
Important properties of mental simulation

- never completely recreate the original experience, but are always partial recreations and can therefore contain biases and errors;
- can be unconscious, as most frequently is the case, or conscious (as in mental imagination).
Mental simulation is a strategy available to humans to reason about mechanical systems (Hegarty, 2004).

**Pulley problem**

The diagram depicts a pulley system. When the free end of the rope is pulled, will the lower pulley turn clockwise?

**Water pouring problem**

The diagram shows two glasses of water. The glasses are the same height and filled to the same water level. If the glasses are tilted, will the water pour out of the two glasses at the same or different angles of tilt? If they are tilted at the same rate, which will pour first?

From Hegarty, 2004 (based on Hegarty, 1992)  
From Hegarty, 2004 (based on Schwartz and Black, 1996)
Visual imagination vs mental simulation

Visual imagination
- Holistic inspection of a mental image of the moving system

Mental simulation
- Piecemeal simulation of the events
- Some information, both visual or otherwise (e.g., force or density)
- Representation of the associated motor actions

(Based on Hegarty, 2004)
Mental simulation in scientific reasoning

- Analogical modeling
- Visual modeling
- Simulative modeling

Nersessian (2008), Clement (2008)
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Scientific modeling and simulation


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Energy2D simulation program.
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Scientific modeling and simulation

WHAT IS THE SYSTEM MADE OF?

HOW DOES THE SYSTEM WORK?
## Scientific modeling and simulation

<table>
<thead>
<tr>
<th>Simulation paradigm</th>
<th>What</th>
<th>How</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equation-based Modeling</td>
<td>A collection of homogeneous elements</td>
<td>Aggregation</td>
</tr>
<tr>
<td></td>
<td>A continuous substance</td>
<td></td>
</tr>
<tr>
<td>Molecular Dynamics</td>
<td>A collection of homogeneous elements</td>
<td>Direct representation</td>
</tr>
<tr>
<td>Agent-Based Modeling</td>
<td>A collection of heterogeneous elements</td>
<td></td>
</tr>
<tr>
<td>System dynamics</td>
<td>An entity made up by components which perform different functions</td>
<td>Aggregation</td>
</tr>
<tr>
<td>Cell Modeling and Simulation</td>
<td>An entity made up by components which perform different functions</td>
<td>Mechanistic explanation</td>
</tr>
</tbody>
</table>
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The role of language

Based on the LASS theory of conceptual processing (Barsalou et al., 2008)
Grounded and embodied instruction

Knowing a concept means being able to mentally simulate it, which entails the ability to:

- construct an adequate mental model of the concept and run the corresponding mental simulations
- revise a mental model when confronted with empirical evidence of its inadequacy
Grounded and embodied instruction

Difficulties in concept comprehension and conceptual change frequently pertain to:

- lack of domain-specific knowledge (essential for constructing and simulating an adequate mental model)
- high extraneous cognitive load (which exceeds the available working memory capacity)
- difficulty in grounding the new knowledge in an embodied sensorimotor experience
- difficulty in comparing the outcomes of mental simulation with contrary empirical evidence
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Grounded and embodied instruction

Instructional design guidelines

1. Imagine the experiential and verbal input that can be associated with the concept’s comprehension
2. Identify the relative conceptual metaphors and image-schemas underlying this input
3. Devise and design instructional activities that can facilitate mental simulation of the concept (on the basis of the target conceptual metaphors and image-schemas)
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The Epistemic Cycle

Reality → System → Model → Simulation

Action → Comprehension → Revision

Definition → Representation → Exploration

Mental simulation
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References


Thanks for your attention!
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http://simulationandlearning.com