Gesture–Visualise–Simulate: a framework to support the teaching of computational thinking in primary school classrooms

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Abstract
The Gesture-Visualise-Simulate framework describes an ordered progression over three distinct conceptual representations and methods of interaction. The sequence decreases in perceptual detail as recommended by Bruner's modes of representation, and is influenced by recent attempts to apply theories of grounded cognition in an educational setting. The framework will be used to guide the development of an interactive learning environment for use within primary school classrooms. In a computational thinking context, the framework may increase the learner's ability to interpret written code – a crucial component of debugging, refactoring, and extending algorithms – by promoting engagement with perceptual symbols that ground abstract concepts in sensorimotor information.

1. Introduction
The introduction of the English national curriculum for computing has served to highlight how little we know about the development of computational thinking in children aged 5 to 11. Borrowing from established mathematical pedagogy, this study investigates the application of Bruner's modes of representation (Bruner, 1966) – an instructional sequence of enactive (kinaesthetic activity), iconic (visualisation of key attributes), and symbolic (abstract description) – to primary school computing lessons. Bruner proposed that this sequence, inspired by Piaget's developmental stages, should provide an optimum path when learning abstract concepts that cultivates the development of transferable knowledge acquired through physical interaction. Bruner's theory is extended using grounded cognition (Barsalou, 2008), with theories of cognitive simulation (Barsalou's perceptual symbol systems) and cognitive linguistics (Lakoff's conceptual metaphor theory) providing a theoretical foundation. The instructional embodiment framework (building on the embodied educational studies of Glenberg) provide prior research supporting the application of grounded cognition to the development of computational thinking in children (Black, 2012). Kinaesthetic activities are often used in introductory programming lessons, and this project will further explore their application within the scope of grounding gestures, inspired by the work of Goldin-Meadow.

2. The Gesture-Visualise-Simulate framework

2.1. Gesture
Lakoff and Núñez (2000) argue that we use grounding and linking metaphors to understand ideas such as algebra, logic, and sets - some of the foundational concepts in computer science. However, the use of metaphor in computing is often more explicit, from object-orientation to skeuomorphic user interfaces, and can fulfill pedagogical, design, and scientific roles (Colburn & Shute, 2008). Indexing perceptual symbols to their verbal referents has been shown to improve reading comprehension by increasing our ability to derive affordances that guide interpretation (Glenberg & Robertson, 1999). However, constraining these affordances may be crucial when mapping from source to target because an imperfect metaphor may imply impossible actions.

This framework suggests explicitly defining available operations by initially linking them to gestures. Co-speech gestures are argued to be the embodied artifacts of cognitive simulation, with evidence showing their ability to facilitate speech and reciprocally influence cognition (Hostetter & Alibali, 2008). Classroom studies show that verbal instruction can be more effective when accompanied by gesture, and that children's imitation of gesture can improve performance in mathematics tasks (Cook & Goldin-Meadow, 2006).

2.2. Visualise

In comparison to multi-modal cognitive simulation the investigation of visual mental imagery is far more established, with fMRI research again confirming an overlap in the neural circuitry for perception and simulation (Ganis et al, 2004). Visual mental imagery has been shown to offer significant benefits in education, with evidence that concurrent presentation of visual and verbal instructional material promotes learning, further confirming Paivio's dual-coding theory (Mayer, 1994). Imagery is already ubiquitous within computing education, however research shows that the effectiveness of an algorithmic visualisation relies on its ability to promote active learning and not simply that "a picture is worth a thousand words" (Hundhausen et al., 2002). This framework recommends the use of interactive visualisations, manipulated through a touch interface.

2.3. Simulate

Research into the effectiveness of the indexical hypothesis for improving children's reading comprehension have shown that imagined activity after physical manipulation can improve performance over physical manipulation alone (Glenberg et al., 2004), with the authors also stating the importance of metacognitive instruction during this stage. This framework suggests providing learners with written instructions, and prompting them to explicitly engage the mental models developed in the first and second stage, with the aim of reinforcing implicit connections between language and perceptual symbols, and developing explicit problem solving strategies.

3. Future work

The ultimate goal of this project is to develop and evaluate an interactive learning environment that scaffolds progression through each of the three described stages, to be deployed in primary school classrooms. Before development can begin, the validity of the framework itself will be investigated using low-fidelity prototypes, with the aim being to evaluate the effectiveness of the gesture-visualise-simulate sequence (modes of representation) compared to a gesture-simulate sequence (instructional embodiment framework). However, at this stage in the project, it is necessary to explore ways in which programming entities and activities can be represented using gesture, as this is not currently supported in the literature as strongly as the use of metaphor and visualisation.

4. References

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