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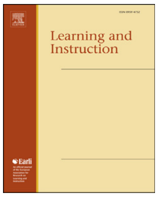

Getting the point: Tracing worked examples enhances learning

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ABSTRACT

Embodied cognition and evolutionary educational psychology perspectives suggest pointing and tracing gestures may enhance learning. Across two experiments, we examine whether explicit instructions to trace out elements of geometry worked examples with the index finger enhance learning processes and outcomes. In Experiment 1, the tracing group solved more test questions than the non-tracing group, solved them more quickly, made fewer errors, and reported lower levels of test difficulty. Experiment 2 replicated and extended the findings of Experiment 1, providing evidence for a performance gradient across conditions, such that students who traced on the paper outperformed those who traced above the paper, who in turn outperformed those who simply studied by reading. These results are consistent with the activation of an increasing number of working memory channels (visual, kinaesthetic and tactile) for learning-related processing.

1. Introduction

1.1. *Cognitive load theory*

Cognitive load theory (CLT; Sweller, Ayres, & Kalyuga, 2011) foregrounds the role of human cognitive architecture in predicting whether instructional designs will support learning. The theory holds effective problem-solving is made possible by a large, well-organised network of schemata held in long-term memory; however, the construction and automation of schemata requires conscious processing in a working memory limited in capacity and duration when information is novel. CLT researchers have tested a range of instructional redesigns targeting different hypothesised sources of working memory load. Earlier investigations (e.g., Cooper & Sweller, 1987; Sweller & Cooper, 1985) focused on redesigns that reduced *extraneous* cognitive load, i.e., working memory processes unrelated to schema construction and/or automation. Subsequent investigations of *intrinsic* cognitive load (e.g., Pollock, Chandler, & Sweller, 2002) theorised this source of load as a function of the number of interacting elements a learner must consciously attend to while learning. Lastly, *germane* cognitive load has been positioned as working memory capacity dedicated to the construction and automation of schemas (Paas & Van Gog, 2006). Recent critiques, however, have argued germane cognitive load can be defined as the working memory resources available to address the element interactivity associated with intrinsic cognitive load (Sweller, 2010).

The current formulation of CLT draws on evolutionary theorizing by Geary (2008), in particular the distinction between biologically primary knowledge and biologically secondary knowledge. The former is held to develop as a natural consequence of human genetic heritage; examples include learning to listen to and speak in a “mother tongue”, or recognise faces. Such skills are held to be acquired without conscious effort. In contrast, biologically secondary knowledge represents the knowledge corpus required to function in contemporary society. Cultural institutions such as schools and universities have emerged to support the slow, conscious and deliberate processes of learning to use historically recent artifacts such as writing systems and mathematics. Paas and Sweller (2012) argue that such evolutionary perspectives on educational psychology may provide the basis for novel cognitive load theory effects, with the potential for biologically primary knowledge to support teaching and learning of biologically secondary knowledge without imposing a substantial additional working memory load on learners. *Embodied cognition*, including the role of gestures in cognition, is discussed by Paas and Sweller as a promising source of evolutionarily informed scholarship for cognitive load theory.

1.2. *Embodied cognition perspectives and the potential of gesturing*

Reviewing the increasing emphasis on embodied cognition in cognitive science, Glenberg, Witt, and Metcalfe (2013) identified

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two general themes in embodiment scholarship. First, thinking is best understood as a function of the brain and the body interacting with the environment; thus, “thinking is grounded in the sensorimotor system” (Glenberg et al., 2013, p.576), rather than consisting of abstract symbol manipulation. Second, the need for the cognitive system to control action, i.e. interact with the environment, acts as a source of evolutionary pressure.

One of the main ways in which we interact with the environment is with our hands. A rapidly expanding body of research has demonstrated that hand movement and position can substantially affect cognitive processing. In particular, pointing gestures, accompanied or not by touch, are of particular interest in the current study for their potential to affect information processing and subsequent learning. For the purpose of drawing attention, a pointing gesture apparently could serve as a primitive but effective attention-guiding cue, as people start using pointing to manage joint attention and interest as young as 12 months of age (Liszkowski, Brown, Callaghan, Takada, & de Vos, 2012). Studies of the interaction between visual attention and hand position also provide strong support for using pointing as an attentional cue. Positioning the hands near an object alters people's visual attention and perception towards that object, so the object will stand out from its surroundings (Cosman & Vecera, 2010), and will be scrutinised longer and deeper (Reed, Grubb, & Steele, 2006). In addition to pointing, hands support direct interaction with the environment through touch, often while simultaneously looking at or listening to stimuli. Similar to research reviewed above, this body of research has found synergistic effects on attentional processes when visual, auditory, and/or tactile inputs are synchronised (for a review, see Talsma, Senkowski, Soto-Faraco, & Woldorff, 2010). For example, Van der Burg, Olivers, Bronkhorst, and Theeuwes (2009) found when participants searched for line segments in a complex display including distractor line segments of various orientations and dynamically changing colour, search time and search slopes were substantially reduced when a tactile signal accompanied the target colour change. Based on studies of spatial cognition, pointing-based cueing may be particularly suitable for instruction with a high spatial content such as geometry, as pointing at an object leads attention to perceive that object in a more spatially oriented way (Fischer & Hoellen, 2004). Dodd and Shumborski (2009) found that encoding spatial arrays with pointing movements towards the visual display led to better memory performance, but not when participants pointed to all objects in an array. While their results indicated enhanced perceptual and motor traces for items selected for action (i.e., through pointing), they also found relatively impaired memory for items that had not been pointed at. Underpinning the various types of conscious cognitive activity discussed above is a working memory architecture consisting of channels for each of the sensory modes. Empirical research on the haptic working memory processor lags substantially behind research on the visual and auditory channels (for a review, see Kaas, Stoekel, & Goebel, 2008). Nonetheless, there is increasing recognition of the intersensory facilitation of visual processing by movement, such that Baddeley's (2012) most recent model of working memory speculates haptic sensory information, including kinaesthetic and tactile input, affects processing in the visuo-spatial sketchpad.

Considering gesture more generally, Alibali (2005) identified a range of ways in which self-generated gestures might affect spatial cognition, including activating both lexical and spatial representations from long-term memory, increasing focus on spatial information, and helping to “package” spatial information with speech (cf. Alibali, Kita, & Young, 2000). This last possibility is particularly germane to the present study, with its focus on cognitive load. Ping and Goldin-Meadow (2010) argued gestures “can provide an overarching framework that serves to organise ideas conveyed in speech, in effect chunking mental representations to reduce the load on working memory” (p.616). In cognitive load theory terms, mechanisms that act to chunk multiple elements of information into a single element are held to reduce intrinsic cognitive load and increase the opportunity for schema construction and/or automation. The present study extends such theorizing, testing if pointing and tracing gestures act to enhance learning of ideas conveyed in printed (textual and diagrammatic) instructional materials.

1.3. Pointing and tracing gestures in education

There is a long history in educational practice of the use of pointing gestures to learn, as well as a gesture incorporating pointing, tracing a surface with the index finger. Learning to recognise letters of the alphabet by “Sandpaper Letters” is a method used extensively in Montessori schools for over a century. Students are encouraged to trace letters cut out of sandpaper with their fingers in the same sequence as writing the letter; while tracing, students simultaneously listen to the sound of the letter pronounced by their teacher (Montessori, 1912). This teaching technique works through a multisensory approach, involving simultaneous input from several modalities; students listen to the sound, look at its representation in the form of a letter, and feel the way it is written as they touch and trace the sandpaper letter.

The learning benefits of tracing have been established across a number of recent experimental studies on letter learning and phoneme identification (e.g., Hulme, Monk, & Ives, 1987) as well as recognition of geometrical shapes in kindergarten children (Kalenine, Pinet, & Gentaz, 2011). Using a within-subjects design, Alibali and DiRusso (1999) tested preschoolers' accuracy in counting chips across a range of conditions (no gesture, puppet pointing, child pointing, puppet touching, and child touching), and found a clear positive gradient in counting accuracy across the above conditions (see Fig. 1, p.46). Alibali and DiRusso speculated the results could be explained by at least two processes: greater proximity of the finger to the chip when touching rather than pointing, and reduced working memory load by providing an external placeholder in the set of counted objects. Drawing on research discussed above, these results suggest the more sensory modalities are activated during the act of counting, the more accurate is performance; however, these results were generated during mathematical problem-solving, rather than instruction.

Taken together, while the existing studies have demonstrated that finger pointing, touching and tracing can enhance task performance, it remains to be established whether such benefits extend to more complex instructions requiring higher levels of abstract thinking and problem-solving skills, and whether a similar gradient in performance is established when additional sensory modalities are recruited during instruction. Moreover, to the best of our knowledge, evidence for cognitive load explanations of pointing and/or tracing effects on learning outcomes – such as through subjective ratings of cognitive load – has not yet been provided. (In contrast, there is substantial evidence from dual-task studies for gesture's effects on cognitive load while processing information more generally; e.g., Ping & Goldin-Meadow, 2010).

In an initial attempt to investigate pointing and tracing effects on cognitive load and learning, Macken and Ginns (2014) hypothesised that explicit instructions to point to related text and diagrammatic elements on heart anatomy and physiology, and trace out arrows indicating key blood flows across the heart's chambers, would enhance learning as measured on terminology and comprehension tests. Large statistically reliable effects of pointing and tracing were found on the above tests; however, there were no significant differences in post-instruction cognitive load ratings between conditions. Thus, a cognitive load