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Review

Examining whether touch sensory feedback is necessary for science learning through experimentation: A literature review of two different lines of research across K-16

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A B S T R A C T

The focus of this paper is on the contribution that active touch sensory feedback offered through physical or virtual (with haptic feedback) manipulatives, makes to students' learning through science experimentation. Both theoretical perspectives and empirical evidence are presented. The theoretical perspectives were drawn from two types of theories, namely *embodied cognition* and *additional (touch) sensory channel*, which were associated with the use of physical and virtual manipulatives for learning purposes. The empirical evidence was drawn from two different lines of research. The first line of research involves studies that have focused on comparing physical manipulatives and virtual manipulatives (without the provision of haptic feedback), whereas the second involves studies that have focused on comparing virtual manipulatives with and without the provision of touch sensory (haptic) feedback. Both theories supply strong arguments for providing touch sensory feedback during science experimentation, whereas the empirical research outcomes show that providing touch sensory feedback is not always a prerequisite for learning science through experimentation. Those instances for which touch sensory feedback does appear to be a necessity for learning science through experimentation are identified. However, science education studies are limited within the aforementioned research areas. In addition, their findings are inconsistent, especially for the research focused on comparing virtual manipulatives with and without haptic feedback. The latter makes it difficult to arrive at a solid framework that depicts when and how touch sensory feedback should be offered to students for learning science through experimentation. The article concludes with suggestions for future research that would contribute towards development of such a framework.

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1. Introduction

One of the major issues researched and discussed over the last few decades concerning learning through science experimentation is the importance of having physical hands-on experience, especially the presence of touch sensory input/feedback, during experimentation (de Jong, Linn, & Zacharia, 2013; Kontra, Lyons, Fischer, & Beilock, in press; Zacharia, Loizou, & Papaevripidou, 2012). Touch sensory feedback refers here to a discovery mode that involves actual and active/intentional tactile actions through which an object's characteristics (e.g., hardness, texture, weight, inertia, geometry/shape, smoothness, temperature, etc.) are perceived by someone through tactual/haptic sensation (Loomis & Lederman, 1986). Touch sensory input is involved in science experimentation when tangible manipulatives are used. These tangible manipulatives can be physical or virtual in nature. In the case of Physical Manipulatives (PM; use of real world physical/concrete material and apparatus), students are always exposed to touch sensory feedback by simply touching the physical material and apparatus that are involved in an experimental procedure with their hands, whereas in the case of Virtual Manipulatives (VM; use of virtual apparatus and material that exist in virtual environments, such as computer-based simulations), students are not exposed to touch sensory feedback unless the virtual lab used includes a haptic device (tactile feedback device), a situation labeled for the purposes of this review as haptic VM, in contrast to basic VM without such haptic devices.

The importance of the presence of touch sensory feedback in science experimentation has inspired two lines of research. The first research direction addresses whether basic VM can be used for experimentation purposes instead of PM, and the second line concerns research on whether haptic devices should be included/added in VM environments such as virtual labs (simulations), comparing basic VM and haptic VM.

Although both of these research directions are grounded on theories that support the presence of touch sensory feedback during experimentation, the relevant empirical studies so far have revealed contradictory findings (in the sense that touch sensory input does not always appear to have added value). For example, research comparing the use of PM and basic VM (without haptic devices) has revealed instances in which the use of PM, with touch sensory input always inherently available, was more conducive to students' science learning than the use of VM (Zacharia, Loizou, & Papaevripidou, 2012), instances in which the use of VM was more supportive than the use of PM (Finkelstein et al., 2005; Zacharia, 2007; Zacharia, Olympiou, & Papaevripidou, 2008), as well as instances in which the use of VM and the use of PM were equally supportive for learning (Triona & Klahr, 2003; Zacharia & Constantinou, 2008; Zacharia & Olympiou, 2011). Based on the latter two findings of these comparative studies, several scholars have argued that the presence of touch sensory input, as such, might not always be a prerequisite for science learning through experimentation (e.g., Triona & Klahr, 2003; Zacharia & Olympiou, 2011). They argued that it is rather the process of manipulation that needs to be present during experimentation and that manipulation does not necessarily require touching the material and apparatus involved in an experiment (e.g., as in the case of basic VM). Manipulation requires the learner to intentionally interact with the material and apparatus in a skillfull manner. However, the use of PM involves certain motor skills that differ from those involved in VM use. For instance, students using PM grab and heft with their hands for manipulation purposes, whereas basic VM users point, drag and click with the mouse or touch the screen with their hands (Triona & Klahr, 2003). It should be noted, however, that the findings of this line of research should be treated with caution since PM and VM differed in other ways than provision of touch sensory feedback in most of the comparative studies conducted so far. Besides touch sensory feedback (provided only through PM), PM and VM differed in other affordances as well (e.g., VM provided representations of conceptual/abstract objects, such as vectors, particles, etc.) (for a review see de Jong, Linn, & Zacharia, 2013).

Another example of discrepant research outcomes can also be drawn from the second line of research, which involves studies that have focused on comparing basic VM and haptic VM. These studies also revealed instances in which the presence of touch sensory feedback was beneficial (Bivall, Ainsworth, & Tibell, 2011; Brooks, Ouh-Young, Batter, & Kilpatrick, 1990; Dede, Salzman, Loftin, & Ash, 2000; Hallman, Paley, Han, & Black, 2009; Han & Black, 2011; Jones, Andre, Superfine, & Taylor, 2003; Jones, Minogue, Tretter, Negishi, & Taylor, 2006; Minogue & Jones, 2009; Reiner, 1999; Schönborn, Bivall, & Tibell, 2011) and instances where it was not (e.g., Bivall et al., 2007; Minogue, Jones, Broadwell, & Oppewall, 2006; Wiebe, Minogue, Jones, Cowley, & Krebs, 2009).

Given these inconsistent research outcomes (in the sense that touch sensory input does not always appear to have added value), several questions are raised: Is touch sensory feedback an important aspect of science learning through experimentation? Does it always need to be present during science experimentation? If so, why are there inconsistencies in the