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GESTURE-BASED LEARNING WITH ICT

Recent developments, opportunities and considerations

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A recent increase in technologies that allow for tactile or embodied experiences presents an opportunity to explore the effect of movement on learning within a cognitive load theory framework. One of the first ICT tools that provided tactile or embodied experiences for students was the interactive whiteboard (for a review see Smith, Higgins, Wall, & Miller, 2005) with more recent examples being smartphones and tablets (Sheu & Chen, 2014). As these touch-based technologies become more readily available in schools, the opportunity to investigate their effects on learning can provide valuable insights to educators.

This chapter first provides an overview of research into gestures within the context of ICT, followed by a study currently in progress that illustrates how research is being conducted to capture hand gestures on touch-based devices. Possibilities for future inquiry within the framework of the human motor system and cognitive load theory are then discussed, as well as implications for the integration of gesture-based ICT tools into instructional practice.

Cognitive load theory and gesture research

Cognitive load theory has identified several empirically supported effects that can inform instructional interventions to support learning (Kalyuga, Ayres, Chandler, &

Sweller, 2003; Mousavi, Low, & Sweller, 1995; Sweller, Ayres, & Kalyuga, 2011; Tindall-Ford, Chandler, & Sweller, 1997). Research has demonstrated that certain approaches to the design of learning materials and the associated activities derived from the design, can enhance learning due to learners' efficient use of limited cognitive resources. For example, one effect, the modality effect, has shown that when students are given learning materials containing diagrams and corresponding audio narrations in the place of expository written text, this dual-modality presentation can provide learning benefits. A key study that demonstrated this effect was Mousavi, Low, and Sweller (1995), where children were provided with worked examples in geometry. The first group was given worked examples with diagrams and written statements describing them, the second group was given the same diagrams and written statements and also listened to a corresponding audio statement played through a tape recorder. The third group was presented with a diagram and audio statement alone, but no written text. Results suggested that students presented the diagram with audio and no written statements completed questions faster than the other two groups. Tindall-Ford, Chandler, and Sweller (1997) found a similar effect with electrical apprentices studying electrical engineering materials. This study found that test scores were higher in a mixed mode condition. Similar to the modality effect, Mayer's Theory of Multimedia Learning (Mayer, 2009; Mayer & Moreno, 1998) applied the same principle of combining visual and auditory materials to multimedia animations, further informing the use of audio-visual technology to support learning.

The effectiveness of using audio-visual instructions is explained within a cognitive load theory framework by dual modality presentations using both auditory and visual channels in working memory rather than just the visual channel. Over the last ten years there has been a shift in cognitive load theory research exploring the use of learning strategies that incorporate the human motor system. This research has extended beyond learners being presented with audio and visual instruction to leverage the use of gestures in support of working memory processes. While it is argued that audio-visual instructions support learning through the use of co-reinforcement of novel information across modalities, using movements like gestures may also provide similar support by freeing up, or more efficient allocating of limited working memory resources. A synthesis of this research will be provided next to illustrate the key findings and highlight areas of emerging research in how the human motor system can support learning.

Human movement effect

Within cognitive load theory research, the human movement effect refers to the benefits of observing human movements when learning to perform motor tasks. This effect was identified after a series of experiments exploring the use of instructional animations found evidence that animations related to procedural motor tasks proved more effective for learning than the equivalent static materials. Two studies were critical in highlighting the efficacy of human movement for learning. Wong et al. (2009) presented learners with an animation depicting origami being folded from a first-person perspective, without showing hands. When compared with learners who were given static images to guide their paper folding, the learners who watched the animation demonstrated higher learning outcomes. Ayres, Marcus, Chan, and Qian (2009) found similar results in a study exploring the learning of knot-tying, with one group of learners looking at static images, and the other at animations of hands tying the knot, with the latter demonstrating increased learning outcomes. From a cognitive load theory perspective, this may suggest that observing human movement may free up, or more efficiently allocate, limited working memory resources that can be used to focus on other task-relevant goals. This theoretical advancement provided some insights into why the observation and physical replication of motor tasks may be beneficial for learning.

Given that human movement like gestures may free up limited working memory resources when learning procedural motor tasks, it may be hypothesised that self-gesturing may support mental simulation of a task when learning to solve a problem. In one recent study, when participants were given the Tower of Hanoi puzzle to solve, results showed that those who gestured had lower saccadic eye movement counts when compared to those who did not gesture (Pouw, Mavilidi, van Gog, & Paas, 2016). Eye movements have been found to provide a support mechanism for visually indexing information during visuospatial problem-solving tasks, with the quantification of saccadic eye movements indicating a measure of cognitive processing. It is thought that gesturing can assist in problem solving by externalising working memory processes, and as a result reduces cognitive load. The research showed that observing and making gestures may play an important role in learning and problem solving in certain contexts. While research within the confines of cognitive load theory has contributed to advancing our understanding of the human motor system's role in learning, other areas of research have also provided an understanding of the benefits of human movement for learning, albeit from different theoretical perspectives. The next section provides an overview of key findings of the benefit of movement for learning from different theoretical perspectives and how these research findings can contribute to cognitive load theory research and increase our understanding of how gestures affect educational experiences.

Embodied cognition

After the human movement effect provided theoretical grounding for the benefit of gestures within cognitive load theory research, Paas and Sweller (2012) identified a separate field of psychology, Embodied Cognition (Foglia & Wilson, 2013), as a framework for future studies investigating human movement. Embodied cognition posits that all cognition, including information processing, learning and problem solving is integrated with all types of sensory input including visual, auditory and human movement. When traditionally explored modalities such as visual and auditory information are coupled with physical experiences, cognition and schema acquisition is also supported (Barsalou, 1999). By assuming that a learner's body movements, including gestures, tactile and touch experiences, as well as their motion through an environment may support learning, subsequent studies within cognitive load theory began to incorporate embodied cognition as a supporting source of knowledge.

Through an examination of learning environments such as classrooms and early learning centers, a body of literature has grown around exploring the use of gestures in more traditional educational contexts. Research by Goldin-Meadow and others (Cook, Duffy, & Fenn, 2013; Cook, Mitchell & Goldin-Meadow, 2008; Goldin-Meadow & Cook, 2009; Goldin-Meadow, & Cook, 2009; Goldin-Meadow et al., 2012; Montessori, 1912/1964) has explored the role of pointing and gestures that represent concepts or processes in children's learning of math and language. This research has provided evidence that gestures can support learners' understanding of novel concepts, which is evidenced through increased learning outcomes. Though this work is not firmly grounded in an embodied cognition framework, the findings may be interpreted as such, while at the same time providing further evidence for the positive role of gestures in classroom-based learning.

Hand gestures have also been shown to benefit foreign languages learners in the classroom (Macedonia & Klimesch, 2014; Mavilidi, Okely, Chandler, Cliff, & Paas, 2015). When participants produced gestures representing an action associated with a novel word or phrase in foreign language learning, such as acting out the word for "swim" while learning the word in Italian, increased recall of these novel words was demonstrated. Further, when full-body movement was compared with arm and hand gesturing while sitting, the learners that engaged in full-body movement benefitted further (Mavilidi, et al., 2015). This study situated within the Embodied Cognition literature used iconic gestures (pretending to act on non-present objects) for learning novel vocabulary. This same type of gesturing can support mimicry. Novack, Goldin-Meadow, & Woodward (2015) showed that when an infant observed an adult demonstrate how a toy worked through an iconic gesture, an infant's ability to successfully operate a toy increased. Within the framework of cognitive load theory and embodied cognition, research into the cognitive function of gestures is presenting many interesting advances. With the increased use of touch-based technologies in classrooms, research that examines gestures facilitated through technology may provide evidence to inform how gestures and ICT may be integrated effectively to support student learning. The section that follows, discusses current research into gesture-based ICT and argues that further exploration of gesturing within ICT may provide important insights into learning, as technological affordances continue to advance.

Gesturing and ICT

While the modality effect and Mayer's Theory of Multimedia Learning (Mayer & Moreno, 1998; Mayer 2009) describe the benefits of simultaneous visual and auditory learning materials, these frameworks for multimodal learning experiences historically did not explore gestures. This may be due to a lack of exploration involving gestures at the time, as well as an absence of the technologies required to accurately record these movements. Recent studies exploring the use of pointing and tracing gestures may serve as foundational work for extending these frameworks by leveraging touch-based technologies to investigate more active physical engagement with ICT-based learning materials.

Macken and Ginns (2014) investigated the relationship between gesturing and learning. This foundational study demonstrated that learners who pointed to particular key medical terms on a paper-based diagram of a heart, benefited from increased learning outcomes, when compared with those who did not point. Additionally, the research showed that learners who traced along paths of blood flow on a diagram of a heart demonstrated greater understanding of the content, compared to those that did not trace. Research by Hu, Ginns, & Bobis (2015) showed the practical use of self-gesturing by having learners trace worked examples of angles in geometry. Results showed that students who traced angles outperformed those students who did not, a finding supported by related research in the area of experimental psychology. Multiple studies investigating child development have suggested that attention is prioritised near the hands, suggesting that the hands provide a joint attention mechanism tied to the early language acquisition in the early years of life (Abrams, Davoli, Du, Knapp, & Paull, 2008; Liszkowski, Carpenter, Henning, Striano, & Tommasello, 2004).

A number of studies have expanded upon pointing and tracing to leverage the affordances of touch-based ICT tools. Agostinho et al. (2015) extended Hu and Ginns' work in a study that investigated the effect of children tracing on an iPad while learning how to understand temperature line graphs. Results demonstrated that those who traced scored higher in transfer tests than those who did not. The results from this study are supported by Lee's (2015) research that found students' learning about the heart using a touch-based device who tapped the screen to focus attention on specific structures performed better on a post-test identification task than students who used a traditional keyboard and mouse-based PC to learn the same information about the heart. Similar benefits of hand gestures were found for a basic mathematics estimation task using iPads (Dubé & McEwen, 2015). In this study students were either asked to point on a line or drag along a slider to estimate quantities. The research shows that the dragging condition led to higher learning outcomes when compared to simply pointing. While these gestures function primarily as a means to control the user interface to specify quantity, they could also be interpreted as interactions that reinforce the relationships between concepts in that a sliding movement better aligns with estimating quantity than pointing. When considering previous research that has focused on pointing and tracing on paper, these ICT-based studies are of interest given that they provide learners the opportunity to directly interact with dynamic multimedia learning materials, a learning experience not possible prior to the advent of tablets and smartphones. Though additional research is needed, studies investigating gesture-based ICT tools in educational contexts have suggested that gestures related to reinforcing and establishing relationships between concepts can benefit learning. The underlying explanation of these results is still yet to be firmly established, though it is possible that attentional and embodied experiences can act as a form of reinforcement, much like an audio narration which reinforces the content of visual learning materials.

Incorporating gestures to support learning has consistently demonstrated benefits through the embodiment of concepts and objects, attention guidance and problem-solving simulation, but in the context of ICT use, there are questions that remain to be answered. Given that the investigation of hand gestures and how they affect learning is still a growing area of research, we still do not understand how the different types of gestures such as pointing and tracing, may affect learning in different ways. It is also important to consider the cognitive function that these gestures play, as previous studies have explored both conceptually linked gestures, and gestures that merely guide attention, such as pointing. As stated by Sheu and Chen (2014, p.276) in their review of research in gesture-based computing, "innovative cross-disciplinary research and related publications that document specific gesture-based learning systems and their associated designs are now vital". In the next section we outline a novel study in gesture-based ICT-supported research that may provide further insight into the benefits of gesturing coupled with educational technologies.

Exploring gestures with the use of ICT

A study to explore multiple types of gestures through touch-based ICT materials has been recently undertaken by Sepp, Tindall-Ford, Agostinho, and Paas. This research investigates how high school students' learning performance and cognitive load is affected by observing and making different finger-based gestures while working through an audiovisual geometry lesson on an iPad. The iPad is a multi-touch tablet device increasingly ubiquitous in educational contexts. The lesson presented on an iPad focuses on learning to solve for angles on a parallel line by presenting a number of worked examples to demonstrate the steps involved. Students watched different versions of the multimedia lesson corresponding to one of four conditions:

1. no animated cues and no gestures performed.
2. animated hands shown tracing along key angles and no gestures performed.
3. animated hands shown pointing on key angles and pointing gestures performed.
4. animated hands shown tracing along key angles and tracing gestures performed.

For the purposes of this study, pointing gestures are considered to focus attention for the learner, whereas tracing gestures (or "embodied" gestures) are considered to physically embody aspects of the problem-solving strategy, in this study the relationship between angles. This study's primary goal was to:

i isolate attentional gestures which focus learner's attention to these angles (e.g. pointing at two equal angles). (Groups 1 & 2)
ii isolate "embodied" gestures that physically represent aspects of the problem-solving strategy (e.g. tracing along two equal angles). (Groups 3 & 4)

A secondary goal of the research was to explore how observation and performance of these gestures affected learning in different ways.

While this study is continuing, the methods presented below may provide a foundation for future studies in gesture-based research. A custom ICT tool was developed which displayed interactive worked example lessons, and also served as the primary means of collecting gesture-based data. During the experiment, participants worked through a custom-designed application or "app" created specifically for the iPad. The app (called Geometry Touch) included audiovisual lessons on geometry, specifically focusing on learning how to solve for angles on a parallel line, along with test questions on concept recall, and near and far transfer of knowledge. Each lesson was presented as a video, which included integrated worked example diagrams, and accompanying audio explanations. Diagrams and worked examples were visually presented as static learning materials, with specific animated hands overlaid for each condition (See Figure 11.1).

While participants worked through the lessons and test questions, their interactions with the touch screen were recorded through the software. Leveraging touch-based technologies provided the researchers with invaluable insight into how students physically engaged with the lesson, including which gestures were performed and when, whether they complied with instructions and how they gestured outside of expected norms, such as touching the screen to aid solving maths problems or simply tapping to focus their concentration. It was critical the students not be distracted or supported by any lines digitally drawn on the screen and so, as they worked through each lesson, every touch registered on the iPad's screen was

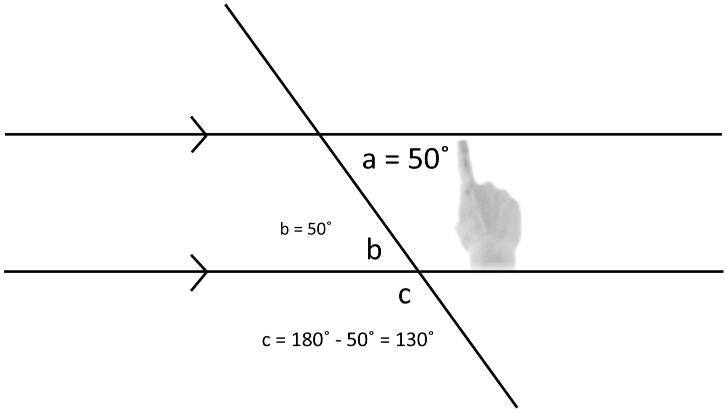

FIGURE 11.1 Animated hand shown during lesson on Geometry Touch iPad App

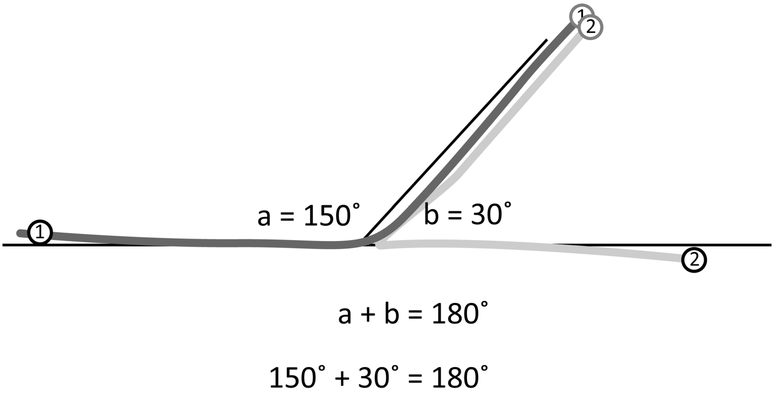

FIGURE 11.2 Tracing gestures captured from Geometry Touch iPad app

recorded, but not displayed. These touches were then rendered and saved by the app for later analysis as visual and quantitative data. As shown in Figure 11.2, the app takes a "picture" of each participant's gesture performance for every screen they are asked to interact with. The lines in the image along with the numbered circles indicate the path and sequence tracing gestures along with their direction with green circles indicating the start of a trace and red circles indicating the end. The color of the line (represented by yellow to red shading) represents the speed of the gesture from slow to fast. In addition, the maximum, minimum and average of any sustained touches such as traces were recorded as numerical data. This study provides a novel methodology for observing the physical interactions participants have with ICT learning materials. In the next section, a discussion of how this study may inform future research is presented, including integration with emerging technologies such as Virtual, Augmented and Mixed realities, and how these technologies may affect learning.

Discussion: possibilities and considerations

The integration of gesture-based learning materials and apps is already taking place in many classrooms and other educational contexts. Digital learning environments including web apps, mobile apps and other emerging technologies are blurring the line between physical and screen-based learning. It may be argued that within these environments, the human motor system may support learning, with further research providing insights into the cognitive benefits that these physical actions provide.

Historically, ICT tools within the context of educational research have been used for the unidirectional presentation of information and indirect interaction with learning materials through a mouse or keyboard. The aforementioned study leverages novel research methods for the capturing of participants' direct physical engagement with learning materials beyond direct observation or video recordings.

This is significant because technologies now exist that allow researchers and educators alike to capture the physical movements of learners as they interact with virtual objects and learning materials while working to solve problems. This capturing of physical interactions may constitute an expansion of available learning analytics to provide "physical learning analytics", which can inform the future design of learning materials and experiences.

With regards to gesture-based research within the framework of cognitive load theory, leveraging the affordances of new technologies presents exciting opportunities for future research. Our study presented a method for isolating the effects of different types of gestures by capturing the physical interactions that the participants had on a touch-screen with two-dimensional learning materials focusing on geometry. There are, however many technologies that are available that now support tracking movement in three-dimensional space: Virtual Reality (VR), Mixed Reality (MR) and Augmented Reality (AR). These technologies immerse the user in computer-generated virtual worlds or overlay digital images, objects or information over real world environments. These technologies push beyond the presentation of learning materials on a screen, to immerse the learner in real or virtual applications of concepts. This is accomplished by tracking their hand, head, eye and even full body movement through a confined physical space, with the learning environment responding to their physical actions. Having access to this tracking information opens many doors for future studies within cognitive load theory and embodied cognition research, especially with regards to how it can inform our understanding of attention and embodiment. By capturing how learners are physically engaging with these environments, we can gain a unique understanding of how these actions may support learning.

Before taking a leap of faith into virtual worlds (VR), researchers should consider that results for studies conducted in the real world may not apply in virtual ones. Ongoing studies in psychology and other areas are continuing to investigate how cognition and motor function differ in VR, so it is important to first replicate existing studies in these environments to confirm that the same rules for perception and cognition apply. By reaffirming that cognitive load effects still apply in VR, we can start exploring new areas with a robust foundation, confident in our assumption that the modality effect, human movement effect and the benefits that gestures make to learning, may translate into the virtual world. Though emerging technologies including VR, MR and AR may not currently be present in every classroom, the next section provides important implications for more ubiquitous gesture-based technologies and how they may best support learning and instruction.

Implications for educational practice

Touch-based technologies such as smart phones, tablets and other portable computing devices present unique opportunities for instructional practice. When considering the use of these technologies for teaching, findings within gesture-based research can inform decisions regarding how they may be implemented effectively. Presented below are two recommendations for considering the use of apps and touch-based ICT tools.

Apps that encourage gestures that are not conceptually aligned with the learning materials may not offer the same benefits as those that do.

Questions remain around the cognitive function of gestures, with regard to their support of attention guidance and conceptual reinforcement. When choosing apps for use in the classroom, the ways in which they encourage human movement and gesturing should be a primary factor in that choice. Apps that encourage gestures for attention guidance and clarification of information related to learning, may provide cognitive supports that lead to increased outcomes whereas apps that only include gestures for navigation and other superfluous tasks may not. As gesture-based technologies become more common, research that investigates how these tools affect cognition can provide important insights into how the human motor system can enhance learning. As we continue to experiment in the classroom, and to investigate through research, it is important to think critically about how our bodies interact with technology, because while there may be an app for everything, an app may not always be the best solution.

ICT Tools that provide opportunities for observing and making gestures can support learning and problem solving.

Whether it be for presentation of content, learning motor tasks or assessment and reflection, giving students opportunities to both observe and actively perform gestures and other movements while using ICT should be leveraged whenever possible. In early learning contexts, games and play are a common strategy, but as students age, it is generally assumed that they are relegated to seated rows and note taking. Current studies demonstrate that even with the use of ICT tools, the human motor system may play an important role in facilitating the learning process, regardless of age. Instructional strategies may include embedding hand gestures in an online lecture to bring attention to key points, leveraging the physical sensors in smartphones to play games in the classroom, or simply to encourage the use of pointing and tracing when engaging with digital learning materials. Given that an array of ICT tools are now available to many learners, instructors should consider the advantages that movement can bring to their students' learning experiences, beyond those of being motivating and different. If using a certain tool results in students being less physically active, or if they are passively engaging with materials that do not take advantage of the benefits that movement can bring, that tool may not encourage learning in the ways that another tool, or even a more traditional approach might. It is important then, to consider how educational technologies can build upon traditional teaching by incorporating gestures and other movements to benefit learning.

Conclusion

This chapter has provided an overview of the current state of gesture-based research within cognitive load theory, along with an emerging area of inquiry around the use of touch-based ICT tools. An in-progress study, which uses ICT to present learning materials while simultaneously collecting gesture data was discussed in terms of future directions for cognitive load theory research. Instructional implications for the use of gesture-based apps and ICT tools were then presented to ground current findings in educational practice. As research into the benefits of hand gestures and movement continues to provide important insights for learning, the incorporation of gesture-based ICT tools into this research can build upon existing findings to inform future educational practice.

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