Eliciting Predictive Behaviors to Support Embodied Mathematical Cognition: Socially-distanced Experimentation in the Time of COVID-19

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Abstract: This study documents the re-design of a remote-learning experiment. Students are prompted to elicit predictive behaviors to test hypotheses about embodied geometric reasoning. To support embodied learning and research online, we re-evaluated the usage of online tools and adapted methodological protocols. Conducting embodied experimental research using web-conferencing platforms challenges how learners communicate the full scope of their understanding in their actions and gestures and how researchers capture that data. This study provides methodological and design-based recommendations for: (1) digital technologies to capture learners' body movements; (2) low-bandwidth stimuli over video streams; (3) instructional scaffolds and (4) visual aids to promote better participation and data collection; and (5) setting up electronic payments for remote remuneration.

Keywords: Embodied cognition, Geometric proof, Online experimentation

Objectives

Amidst a global pandemic, it is critical for researchers to adapt methodological protocols to stipulate the guidelines of social distancing. Depending on disciplines, frameworks, research questions, settings, and outcomes, the impact of a pandemic like COVID-19 forces a wide-range of new strategies and techniques for conducting behavioral research. For researchers of embodied cognition in education, it means preserving the fidelity of interventions, ensuring that actions of the body help connect concepts in the mind, and that the measures of its implementation and the impact on participants are captured in the data. Researchers must transform lab-based, in-person research into "virtually in-person" experiments. Though several studies have explored approaches for managing remote experiments (e.g., Herrera et al., 2006; Kraut et al., 2004), few have investigated how remote environments fit with embodied learning and research. This paper discusses the re-design of a live, remote experiment, in which participants perform physical movements and predict movements in the process of solving geometric conjectures. Researchers offer perspectives on translating a three-dimensional experiment to two dimensions, conducting it, and the lessons learned.

Theoretical Framework

Embodiment in a Virtual Environment

A fundamental idea underlying embodiment is that representations of a concept or object involve sensory, perceptual and motoric re-experiencing of an associated event (Niedenthal, 2007). In essence, embodied learning and knowing requires learners to be engaged in "intercorporeal subjectivity", namely, to meet bodies (Dall'Alba & Barnacle, 2007). Therefore, embodied learning, and embodied research, rely on experiences rooted in bodily perception and action (Lindgren & Johnson-Glenberg, 2013). Unfortunately, virtual and remote environments do not always allow for "fully bodily sensory awareness" to take place (Bauer 2004, p.86). For example, bodies that are "screened" in a text-based computer-mediated environment deprive researchers of opportunities to perceptually grasp learners' gaze, actions, gestures, etc. (Metlevskiene, 2011). While video-conference systems alleviate some of these shortcomings in noticing and capturing non-verbal communications, the windowed display becomes a boundary (Onishi, et al., 2016) that reduces social telepresence and embodied perceptions.

Embodiment as Action as Simulated Action

Our research in embodied learning focuses on the externalizations of cognition via speech and gestures, where gestures simulate actions (Hostetter & Alibali, 2008, 2019). It is hypothesized that people often form gestures as anticipatory simulations, as permutations of (nearly) all of the plausible actions in goal-directed settings (Wolpert et al., 2003), and it is during these goal-directed events that *mental perceptuo-motor simulations* of bodily interactions with the physical world (Barsalou, 2009) couple with cognitive processes. This reciprocal process of coordinating motoric and mental activity is what Nathan (2017) refers to as *Action-Cognition Transduction* (ACT).

Prediction! What a nice gesture?

In ACT, Nathan (2017) posits that inference making based on both body-based feedback and *feedforward* processing (like predictions) contributes to conceptualizations about future states and more generalized forms of reasoning. Rather than awaiting sensory input and being reactive, which can be slow and potentially dangerous, people's cognitive systems continually anticipate (i.e., predict) necessary actions from streams of sensory input. These predictions are foundational for making generalized deductions that increase the probabilities for better outcomes for the person.

Using this theoretical framing, we designed a study to explore the hypothesis that action-based *prediction* will help students formulate generalizations about shapes in space, and in turn foster the formation of mathematically valid geometry proof (Nathan & Walkington, 2017). We explore whether action-prediction of mathematically relevant movements improves student learning with and without the production of directed actions. In light of the COVID-19 pandemic and the need for social-distancing, this experiment (and all non-essential campus research) shifted to online data collection. This required a redesign of the materials and methods that balanced between research goals and ethical concerns about using digital meeting platforms and online tools.

Adapting Embodied Experimentation in a Socially-distanced World

At the core of this intervention-based experiment, participants perform mathematically relevant body movements (*directed actions*) and predict possible future movements of an avatar. Directed action sequences (i.e., a series of posed figures) were created using *The Hidden Village* pose editor (Nathan & Swart, 2020) (see Figure 1). In compliance with federal policies for the protection of human subjects, all data is securely transmitted over virtual private networks (VPNs) and stored on private, firewalled university servers. Table 1 gives side-by-side comparisons between the 3 iterations of this study (re)design.

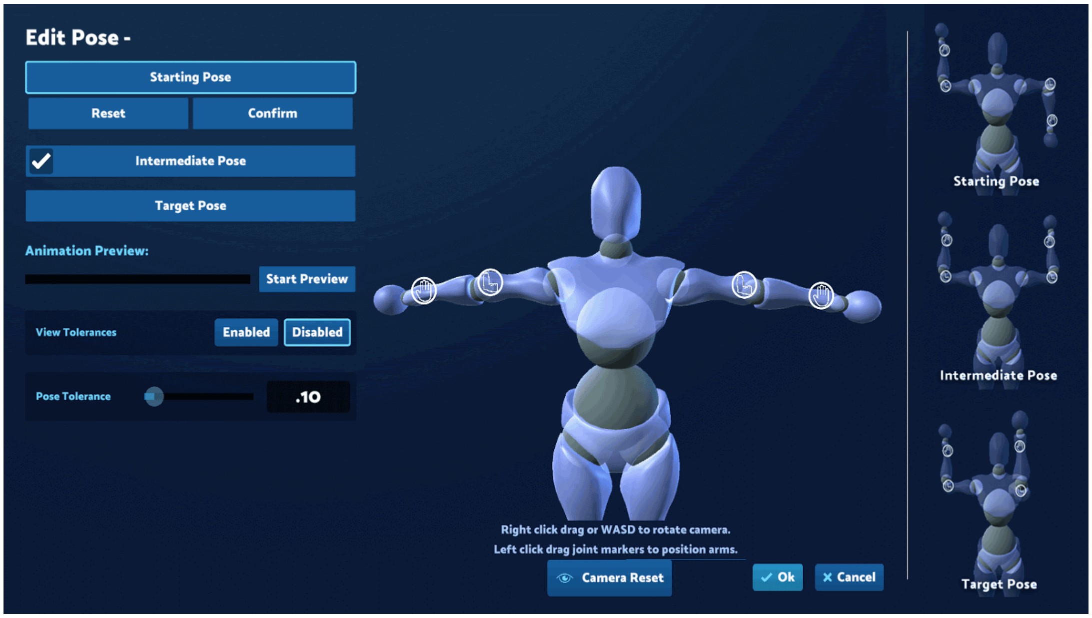


Figure 1: The Hidden Village Pose Editor. *Center*. The avatar that can be manipulated by the user. *Right Column*. Three poses (i.e., starting, intermediate, and target poses) created by the user so they are relevant to the conjecture "If you halve the length and width of a rectangle, then the area is exactly halved.

Table 1. *Comparisons between Iterations 1, 2, 3*

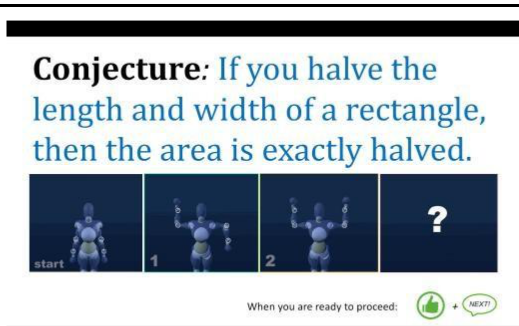
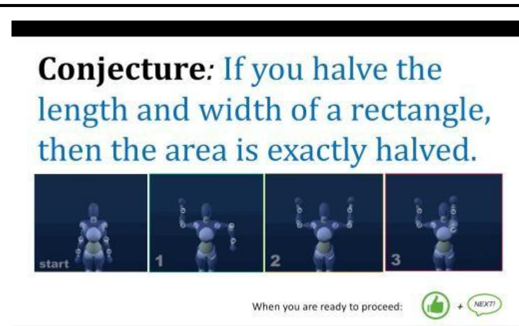
	In-person	**Online (1st iteration)**	**Online (2nd iteration)**
Training/Practice	None	None	Practice trial
Researcher Scripts	Read aloud by researcher	Read aloud by researcher + On-Screen Texts	Read aloud by researcher + On-Screen Text + Icons
Instructions	Read aloud by researcher	On-Screen Text	On-Screen Text + Icons
Conjecture Texts	On Screen	On Screen	On Screen
Directed Actions	A series of 3 static frames shown in succession	A series of 3 static frames shown in succession	2D animation (dynamic movements) + added labels to show the order of the series of actions (i.e., 1, 2, 3)
Software	Slides presented via the researcher's laptop screen.	Participants see slides from their own laptop and researcher appears as picture-in-picture at the bottom left of participants' screen.	
	Cube Camera, Laptop Camera	Participant Web Camera; Researcher Screen Recording	

	PowerPoint	PowerPoint via BBCU	
Recruitment	Paper flyers; In-Class	Emails; Digital Posters In online class	
Data Collection	Video Recording; Audio Recording; Qualtrics (online database); In-Person Observations	BBCU recordings; Debut recordings Qualtrics online; Remote Observations	
Remuneration	Gift Cards	e-Gift Cards	3rd-Party payments via Custodial Account

Original Design

The original experiment was designed as an in-person, 2x2 factorial, between-subjects experiment, to perform *directed actions* (DA=Yes; DA'=No) and generate *predictions* (P= Yes; P'=No) (see Table 2). In a private room, individual participants stood in a private lab room with an experimenter, a computer, and video recording equipment. Participants were prompted to read a mathematical conjecture (see example in Table 2). Next, they were exposed to one of four conditions: (1) Condition DA+P was shown an incomplete sequence of directed actions and then asked to predict a "possible" next movement; (2) DA+P', received the complete series of directed actions but made no predictions; (3) DA'+P, this group was not exposed to DA but was subsequently asked to "imagine" movements that could enact the geometric transformation of each conjecture; (4) in DA' +P' (i.e., the control group), participants received no directed actions and made no predictions. Finally, all four groups completed each conjecture by answering a prompt to consider the veracity of the statement (i.e., *always true* or *false*) and to provide verbal justification.

<u>Table 2.</u> *2x2 Factorial Research Design*

<table>
<tr><th>Prediction X Directed Actions</th><th>Prediction</th><th>No Prediction</th></tr>
<tr><td>Directed Actions</td><td>
</td><td>
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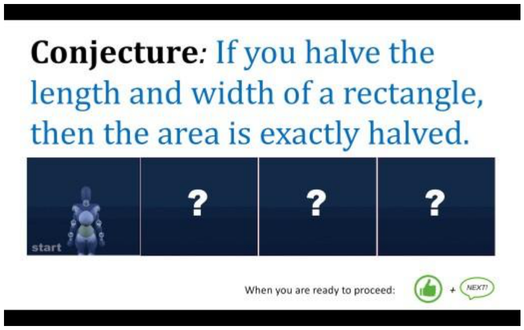
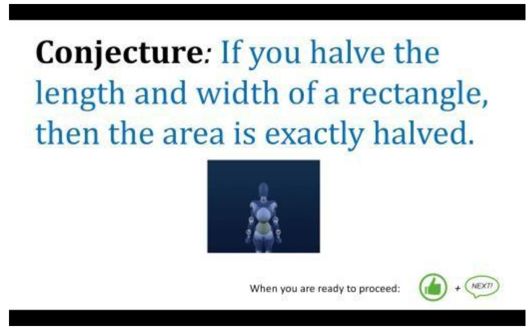
No Directed Actions		

During the experiment, researchers served as facilitators, advancing presentation slides for the participant, qualifying instructions, clarifying questions, reminding participants to read content aloud, and prompting them to provide clear explanations for their rationales. Presentation slides shown on the computer were designed to advance participants through the experiment and to be video-recorded using multiple cameras, (1) a close view of participants and their actions; (2) screen capture of the researcher's computer (including the video conference and the experimental materials).

Iterating COVID Redesigns

Software for distanced research. After trying various digital platforms (e.g., WebEx, Blackboard Collaborate Ultra, Microsoft Teams) in pilot testing, *Blackboard Collaborate Ultra* (*BBCU*) proved a suitable digital platform for the experiment for two main reasons: (1) its availability in our University's software library and accompanying approval as a secure platform for collecting human-subjects research data and connecting to local servers; (2) it allows researchers to simultaneously advance presentation slides while observing participants speech and movements in near full-screen (see Figure 2). Since *BBCU* can only record the presentation and participant audio without video, researchers also licensed a screen recording software, *Debut*, to record participants' movements and interactions with the researchers.

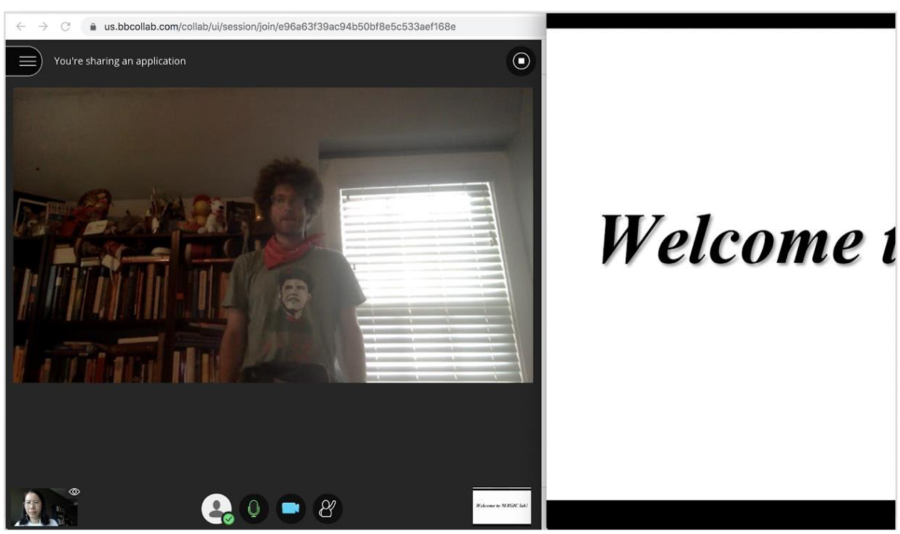


Figure 2: Layout of a researcher's laptop screen. [Left] Researcher's view of participant with thumbnail views in the corners of self and the slide presentation. [Right] The slide presentation the researcher shares with the participant. The researcher advances the presentation slide by clicking on its window.

Conveying directed actions statically. In pilot work, researchers encountered a disruptive discontinuity using video and audio streams with participants. Thus, minimizing bandwidth became crucial to ensuring a reliable trial. In the first online version, directed actions were presented as a series of static images for participants to mimic. However, participants interpreted these slides as individual, unrelated poses, frequently putting their arms by their side between each pose. Since the goal was for participants to perceive the directed actions as continuous movements, researchers needed a way to convey continuity without using a continuous media like streaming video. As a solution, the three static poses were combined into an animated GIF similar to framed 2D-animation depicting continuous (if choppy) movement by the avatar (Figure 3).

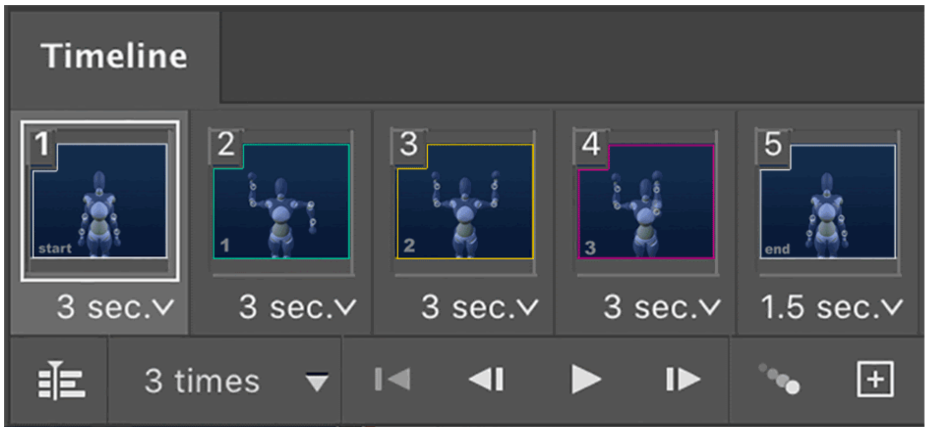


Figure 3. Turning static frames into animations with timing and added visual elements

Refining timing and visual scaffolds of animations. In pilot testing with the new animated GIFs, participants interacted with and remarked on the timing, sequencing, and visual scaffolds for presenting the directed action poses. Fortunately, animated GIFs are customizable and participants' feedback provided important guidance in creating the new stimuli. For timing issues, researchers found that participants were able to perceive directed action poses as continuous at 3 second intervals, which also provided enough time to move their body into position before receiving the next pose. For sequencing and scaffolding, researchers implemented three design changes: (1) adding a neutral beginning/ending pose avatar (to help recognize when a sequence was complete); (2) adding text indicating "Start", "1", "2" and or "3" or "?" or "end"; and (3) adding a border frame using a traffic light colors convention of green (start), yellow (continue) and red (stop) to the 1st, 2nd and 3rd frames of the directed action sequence, respectively.

Adding a practice trial. Unlike participants' in-person trials, online pilot studies revealed that some participants had difficulty understanding how to complete tasks of the experiment until they had encountered multiple conjectures. Students can often engage stimuli in unexpected ways and astray from intended interactions (Trninic, Gutierrez, & Abrahamson, 2011). With only 8 conjectures total, the potential for data loss necessitated that researchers add a practice-trial example conjecture for participants to familiarize themselves with each component of their participation.

Combining textual and visual instructions. The presentation slides in this experiment relied on a combination of text and visuals to ensure that participants had clear directions. For example, we added a picture of the screen layout (see Figure 4) to illustrate how a participant's screen would appear during the experiment to ensure that researchers could capture their entire upper body.
Additionally, researchers designed and added icons (see Figure 4) to help participants navigate through the experiment while minimizing unnecessary cognitive load with additional written

instructions. The resulting combinations of icons with textual instruction improved participants' recognition and comprehension in pilot work.

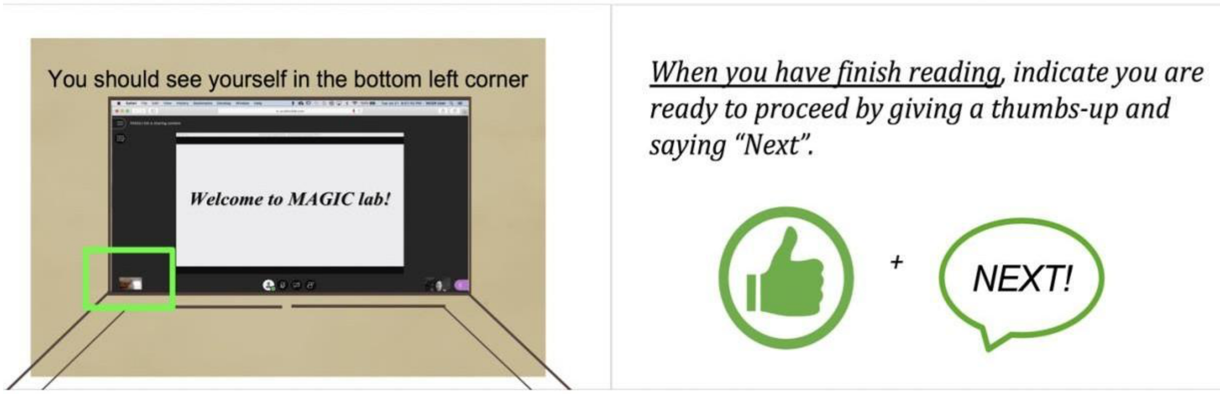


Figure 4. [Left] A picture of screen layout that should be shown on a participant's laptop screen; [Right] Icons designed for Thumbs-up and Next.

Administering electronic payments. Participants were scheduled to receive a $20 gift card to an online retailer as compensation. Social distancing essentially requires researchers to distribute payments remotely, which meant using electronic gift cards. However, as a state-run institution, electronic payments are not allowed for non-US citizens; but with over 4000 international students from over 130 countries at UW-Madison, researchers needed a way to compensate foreign-national participants remotely (per pandemic protocols) without violating state policies. The solution was to set up temporary custodial funds (i.e., a personal bank account registered by the institution) to which departments can distribute grant allocations directly to researchers. In turn, the researcher became wholly responsible for the funds and could thereby side-step the restrictions barring electronic payments and purchase the gift cards and electronically deliver them to all participants. Of note is that researchers made PDFs of emails confirming the purchase, delivery, and transfer of the gift cards as documentation required for custodial fund reconciliation with the university.

Conducting the study

The experiment was conducted in the Fall of 2020. A single researcher, connected with individual participants (n=127) via BBCU and successfully ran the experiment without any major issues. The high-quality screen recording captured participants' speech and upper-body movements and gestures in near full-screen. The 3-second timing intervals of the directed actions animated GIFs provided almost all participants enough time to follow the poses displayed by the avatar without impeding perceptions of continuity of movements. The practice trial proved beneficial as no participants out of 127 performed the experimental conjectures improperly. The instructions and scaffolds appeared to provide clear directions for participants to navigate and complete all aspects of the experiment. One exception was the failure to anticipate that some participants (14%) in the DA'-P condition, who did not have examples of directed actions but were asked to "imagine" possible movements enacted the geometric transformation of each conjecture utilizing their legs. Although the experimenter was able to have these participants adjust their web camera to capture lower-body movement, these episodes highlighted an oversight in the scope of the instructions delivered during the set-up portion of the protocol. Nonetheless, it also introduced another way for participants to embody their learning, the benefit of which could be explored in future research.

Discussion

Research in the time of COVID-19 is revealing changes necessary for adapting the ways to engage and protect participants. These design revisions highlight five considerations to support researchers in embodied education: (1) properly utilizing a combination of revised instructions/scaffolds, web-conferencing platform (e.g., *BBCU*) and a separate screen recorder (e.g., *Debut*) enables researchers to see and record participants' arm and hand movements, which are the primary sources for understanding embodied mathematical reasoning; (2) displaying animated GIFs to convey continuous motions helps minimize bandwidth while maintaining minimal continuity of video and audio streams with participants; (3) providing a practice trial helps participants familiarize themselves with materials and procedures for the experiment helps participants comply with intended interactions (especially since researchers are not privy to how virtual environments and presentation slides appear on participants remote setups); (4) adding visual icons and written instructions to the interface can improve participants' visual literacy, minimize extraneous cognitive load and help stipulate experimenter's expectations and provide good data; (5) exploring alternative payment options might be necessary at respective institutions in order to administer participant remunerations remotely to maintain social distancing standards.

Finally, we consider some limitations of computer-based embodied research. For electronic embodied research, physical movements are as important as the corresponding verbal responses. Often, when participants are seated in front of their computer, the built-in camera merely records the face and shoulders, but a more distanced camera can capture the entire body. Fortunately, slight adjustments in experimental protocols, including software, hardware, and setup can bring the upper and lower bodies of participants into the frame. A second, and very important limitation, is access. Ostensibly, digital divides can potentially lead to sampling bias since computer-mediated online research will only recruit and run participants with sufficient internet access and bandwidth, not to mention the need for a desktop or laptop computer or digital device. In a new experiment, we will explore the delivery of sanitized machines to participants as a way to expand participation. Despite these limitations, educational research must find ways to forge ahead in circumstances that implore remote research. This study provides methodological and design-based solutions for conducting remote embodied research and highlights future directions for the technologically-distanced world of the foreseeable future.

References

Barsalou, L. W. (2009). Simulation, situated conceptualization, and prediction. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1521), 1281-1289.

Bauer, K. (2004). Cybermedicine and the moral integrity of the physician–patient relationship. *Ethics and Information Technology*, *6*(2), 83-91.

Dall'Alba, G. & Barnacle, R. (2007). An ontological turn for higher education. *Studies in Higher Education, 32*(6) 679–691.

Herrera, O. A., Alves, G. R., Fuller, D., & Aldunate, R. G. (2006, August). Remote lab experiments: opening possibilities for distance learning in engineering fields. In *IFIP World Computer Congress, TC 3* (pp. 321-325). Springer, Boston, MA.

Hostetter, A. B., & Alibali, M. W. (2008). Visible embodiment: Gestures as simulated action. *Psychonomic Bulletin & Review, 15*(3), 495-514.

Hostetter, A. B., & Alibali, M. W. (2019). Gesture as simulated action: Revisiting the framework. *Psychonomic Bulletin & Review, 26*(3), 721-752.

Kraut, R., Olson, J., Banaji, M., Bruckman, A., Cohen, J., & Couper, M. (2004). Psychological research online: report of Board of Scientific Affairs' Advisory Group on the Conduct of Research on the Internet. *American Psychologist, 59*(2), 105.

Lindgren, R., & Johnson-Glenberg, M. (2013). Emboldened by embodiment: Six precepts for research on embodied learning and mixed reality. *Educational Researcher, 42*(8), 445-452.

Metlevskiene, L. (2011). Embodiment and embodied learning in online learning environments. *34th Annual Proceedings on the Practice of Educational Communications and Technology*, 414-421.

Nathan, M. J. (2017). One function of gesture is to make new ideas. In *Why Gesture?: How the hands function in speaking, thinking and communicating* (pp. 175-196). John Benjamins Publishing Company, Amsterdam, the Netherlands.

Nathan, M. J., & Walkington, C. (2017). Grounded and embodied mathematical cognition: Promoting mathematical insight and proof using action and language. *Cognitive Research: Principles and Implications*, *2*(1), 9.

Nathan, M. J., & Swart, M. I. (2020). Materialist epistemology lends design wings: educational design as an embodied process. *Educational Technology Research and Development*, 1-30.

Niedenthal, P. M. (2007). Embodying emotion. *Science, 316*, 1002–1005.

Onishi, Y., Tanaka, K., & Nakanishi, H. (2016, October). Embodiment of video-mediated communication enhances social telepresence. In *Proceedings of the Fourth International Conference on Human Agent Interaction* (pp. 171-178).

Trninic, D., Gutierrez, J., & Abrahamson, D. (2011). Virtual Mathematical Inquiry: Problem Solving at the Gestural—Symbolic Interface of Remote-Control Embodied-Interaction Design. In *Proceedings of the Ninth International Conference on Computer-Supported Collaborative Collaborative Learning* (pp. 272-279).

Wolpert, D. M., Doya, K., & Kawato, M. (2003). A unifying computational framework for motor control and social interaction. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *358*(1431), 593-602.