Designing Physical Interventions to Improve Gestural Interactions with Science Simulations

Amanda Henderson, University of Illinois Urbana-Champaign, Champaign, IL, USA, akhende2@illinois.edu

Robb Lindgren, University of Illinois Urbana-Champaign, Champaign, IL, USA, robblind@illinois.edu

Abstract
This paper explores the collaborative process of designing a physical object to support a National Science Foundation funded educational research project. Researchers involved with this project are exploring the ways in which gesture can aid in a student's ability to construct explanations of science phenomena, particularly ones that have unseen structures and unobservable mechanisms. In order to manipulate the science simulations, a motion sensitive device captures students' hand gestures. It can be difficult for students to know how to engage with this device, which impedes both student learning and associated research. In order to reduce usability challenges and enhance the connection between a student's gestures and the scientific concepts presented on the simulation screen, a collaborative and iterative design process was conducted to create a designed form that would assist students in productively engaging with the simulations. The iterative development process of this project is an exemplar of how designed items can be developed to support multidisciplinary research projects, while also creating new fields of research. Future exploration of this device's impact on student interaction and learning may bring to light how objects can change how people gesture in learning contexts, leaving a lasting imprint on their understanding and memory.

Keywords: embodied learning, gesture, educational environments, affordances, human-centered design

Designers are frequently invited to participate in research projects after the study has begun. They are welcomed at a time when the research team has already developed the study, but may be displeased with the aesthetics of the experience. Difficulties collecting data from studies with poorly designed user experiences and interfaces is all too common; and ease of use is seen as correlated with a more "pleasant" appearance, as a result of the aesthetic-usability effect (Lidwell, Holden, & Butler, 2003). In many cases studies require the participant to interact with a screen-based user interface, but the participant's experience of the study is so much greater than simply engaging with the researcher and screen; their entire environment factors into their learning experience. The participant's perception of their environment influences the data collected as well as learning outcomes in the case of an educational research study. This paper discusses the impact of environmental influences on human perception and cognition; explored through the design development of one form, intended to benefit an embodied learning study.

Background

GRASP Project

The GRASP project (GestuRe Augmented Simulations for supporting exPlanations) is a National Science Foundation funded project focused on the impact gesture can have on learning. Gestures externalize and make visible a participant's thought processes while learning new concepts, in addition to potentially increasing understanding and memory of the concept. For the GRASP project, these concepts focus on the scientific areas of thermal conduction, gas pressure, and the changing seasons. Each of these concepts can prove difficult for students to understand as the scientific phenomena themselves are unobservable by the naked eye (e.g., molecules colliding), and using gesture in explanations of these concepts has the potential to increase learning. Middle school students participating in the study interact with a variety of computer-based simulations of these three concepts, interacting with each through a gesture-tracking device called the LEAP motion. In order to engage each simulation the student must use specified gesture conventions within the use-zone of the device; participants are guided to use these gestures by the researcher running the study and the on-screen interface.

Two years into the study, the research team had made significant progress articulating the design considerations of the GRASP study as well as considerations for other studies run in gesture- augmented learning environments (Wallon & Lindgren, 2017). With these considerations in mind, the research team determined that bringing a designer onto the team would help enhance the student experience with the LEAP device and on-screen simulations; and amidst the process of implementing user experience adjustments, an opportunity arose to better the student experience through designed form.

Human-centered Design Process

In order to complete a human-centered design process, a designer must engage with the user experience from start to finish. Exploring all potential interactions and opportunities for user error, confusion, and misunderstanding. Empathic modeling, or placing oneself in the position of a unique user group, can be used to consider the experience from the view of the participant or researcher (Mcdonagh, Bruseberg & Haslam, 2002). Observation and interview are also essential in identifying and predicting user needs (Kelley & Littman, 2001)

In order to test the user experience of the GRASP simulations, it was important to engage firsthand with the experience of the study using only the simulation interfaces as a guide. Relying fully on the simulations and LEAP device for guidance, it was clear which steps in the user experience might be confusing to a new user without researcher instruction. As screen-based changes were identified and observation of researchers working with participants was completed, it became clear that participants were frequently experiencing difficulty understanding where their gestures should take place in the airspace over the LEAP motion device.

The LEAP motion is a small device that offers a low profile system for monitoring gestures, which in turn control computer simulations. While the size of the device is convenient for researchers to carry and setup, there was often interference in the study when student participants struggled to maintain a proper read out from the device. This issue would occur as students' hands moved too high, too low, or out of the zone of readability for the LEAP motion. It became clear that participants could benefit from a physical intervention in their environment. To address problems that students had using the tool, visual cues could be added to indicate the appropriate zone for interaction. This might allow students to offload extraneous thought processes as they participate in the embodied learning activity.

Literature Review

Designing Intentional Environments

Designing an intentional environment in which an embodied learning study will be run, relies heavily on how people perceive and react to elements within their surroundings. Humans experience the world through bodily positioning and senses; according to Johnson (1987), "our embodiment is essential to who we are, to what meaning is, and to our ability to draw rational inferences and to be creative" (p. xxxviii). The situated nature of embodied cognition makes a strong argument for studying the phenomenology of perceived material landscape in order to make more informed design decisions. Each designed form that exists within an environment adds to the material landscape. According to Barsalou (2008) the material landscape as a whole is perceived through the situated nature of all human experience and influences cognitive processes.

Considering a person's surroundings as a pivotal factor in their cognitive processes provides essential information to the human-centered design research process, with the added potential of inspiring awareness of the need for a new product. As Roy Pea (1993) mentions in his paper on distributed intelligence, human cognition relies on perceived elements of environment in order to promote functional interaction. Pea (1993) states:

> …The environments in which humans live are thick with invented artifacts that are in constant use for structuring activity, for saving mental work, or for avoiding error, and they are adapted creatively almost without notice. These ubiquitous mediating structures that both organize and constrain activity include not only designed objects such as tools, control instruments, and symbolic representations like graphs, diagrams, text, plans, and pictures, but people in social relations, as well as features and landmarks in the physical environment (p.48).

Part of this understanding of the environment is based on schemas created over time; including place schemas that help people understand what sort of human activity should take place in an environment (Davis, 2002, p.80-82). As humans gain experience with varying environmental factors over time, they begin to have a better understanding of the affordances of various elements within a space. Affordances, defined by Gibson (1979), are the perceived potential interactions that people have with elements of their surrounding environment. This ability to "read" the functionality of a space provides an interesting opportunity to utilize implied affordances of a space and the physical interventions within it, in order to create an effective intentional environment. By studying perception of affordance, more informed design choices are able to be made in the creation of new forms and spaces where intentional gesture can betied into the interaction. Building gesture into interaction with elements of the space may provide a more memorable and engaging experience, while also providing an additional way for a person to understand and explain a learned concept. As Susan Goldin-Meadow (2011) suggests, "gesture not only presages learning but also can play a role in bringing learning about. Gesture can cause learning indirectly by influencing the learning environment or directly by influencing learners themselves. We can thus change our minds by moving our hands" (p.595).

In order to create environments that reduce cognitive load and encourage intuitive understanding or problem solving, epistemic action must be taken to build designer environments (Clark, 1998, p.511). By creating a built environment with areas structured to take on the weight of thought process, designers can reduce or eliminate cognitive stress points. Margaret Wilson (2002) elaborates on this potential in her third of six views of embodied cognition: people "offload cognitive work onto the environment. Because of limits on our information-processing abilities (e.g., limits on attention and working memory)... we make the environment hold or even manipulate information for us" (p.626). The implications of people using their environment to hold and manipulate information, provides another interesting opportunity for designed interaction. People may be able to use designed forms in the environment to eliminate cognitive stress points, improve learning and memory, and change their understanding of information; which in turn might change their perception of the world around them.

Further considerations regarding the design of the GRASP study can be found in Wallon & Lindgren (2017).

Research Methods

While in the process of improving the aesthetic and user experience of the GRASP simulations, it became clear that there could be an improved interaction with the LEAP motion device through some type of physical intervention that might make the user's gestural experience more intuitive. This designed form's intention is to help study participants understand where their gestures need to take place in relationship to the LEAP device that is tracking their motion, while not interfering with their view of the science simulation they are controlling. Considerations at the start of the design process included the nature of embodied learning, situated cognition, perceived affordances and the potential for cognitive offloading.

Through a collaborative, iterative human-centered design process a hand guide device was developed. This hand guide device was designed in correspondence with the GRASP researchers as they made advancements to the current study; the goal of designing this device was to customize the learning experience of the GRASP study, and help prepare for future iterations of the study.

Observation and Inspiration

Initial experience and observations of interacting with the GRASP simulations and LEAP motion device indicated that there is an optimal functionality zone for the LEAP motion device to properly control the simulations (figure 1). It also became clear that this device would have two very different user interactions. For participants in the study, this device would act as a hand guide that they did not come in contact with, but used as a visual reference to inform their gesture locations. Additionally, based on the function of the LEAP device, students had access to a feedback loop from the simulations, as their gestures either succeeded or failed to control the simulations while referencing the hand guide (Lidwell et. al., 2003, p.

76). Researchers, on the other hand, would be physically interacting with the device: carrying it, setting it up, making adjustments, and referencing it throughout the study.

The researchers needs inspired some of the key features of the device: basic size, need for modularity, adjustability, and identifiable features. The study participant's interactions with the device, in addition to the content of the science simulations (unseen structures eg. molecules), lead to an exploration of ephemeral imagery (e.g., light, particles, ripples in water, natural forms) as well as aboriginal dot paintings; artworks created as a symbolic representation in the process of telling tribal stories, similar to the way gesture can be a physical representation associated with the explanation of a concept.

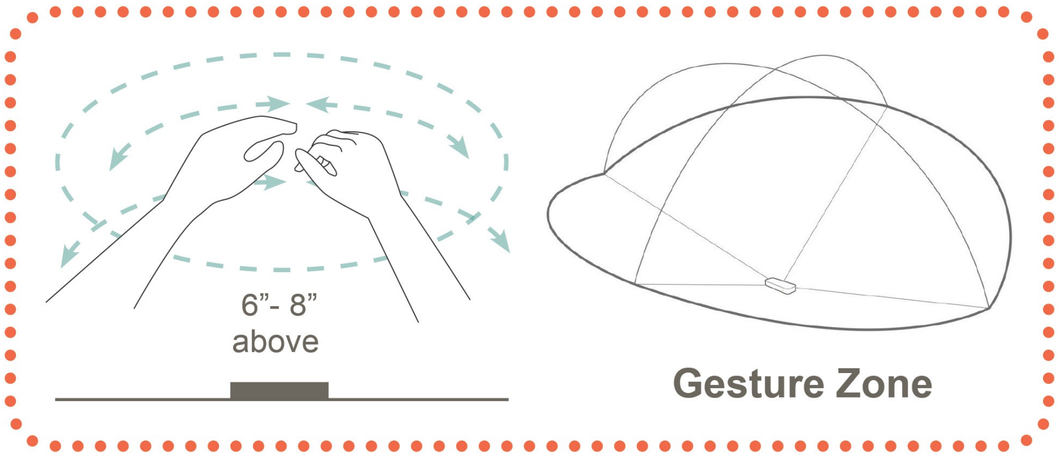

Figure 1: the LEAP Motion device has a specific gesture zone for optimal performance.

Early Sketches and Low Fidelity Prototyping

Early sketches of the hand guide focus on the device's goal of helping study participants visualize the gesture zone where the LEAP device will pick up their motions. This affordance is implied through the use of lines, taking into consideration the gestalt principles of perception: closure and good visual continuation (Ellis, 1999). The device also begins to act as a symbolic barrier between the study participant and the computer screen, with the figure ground relationship of the space contained by the hand guide as the apparent interaction zone (Vecera, Vogel & Woodman, 2002).

Of the initial sketched concepts, one enclosed hand guide and one open format hand guide were chosen by the GRASP research team to be prototyped (figure 3). These prototypes allowed for testing with the LEAP device and simulations. The enclosed hand guide caused some issues with the function of the LEAP device as well as obstructing some views of the simulations. The open format concept can be adjusted for various gesture widths, depending on whether the gesture requires one or two hands in motion.

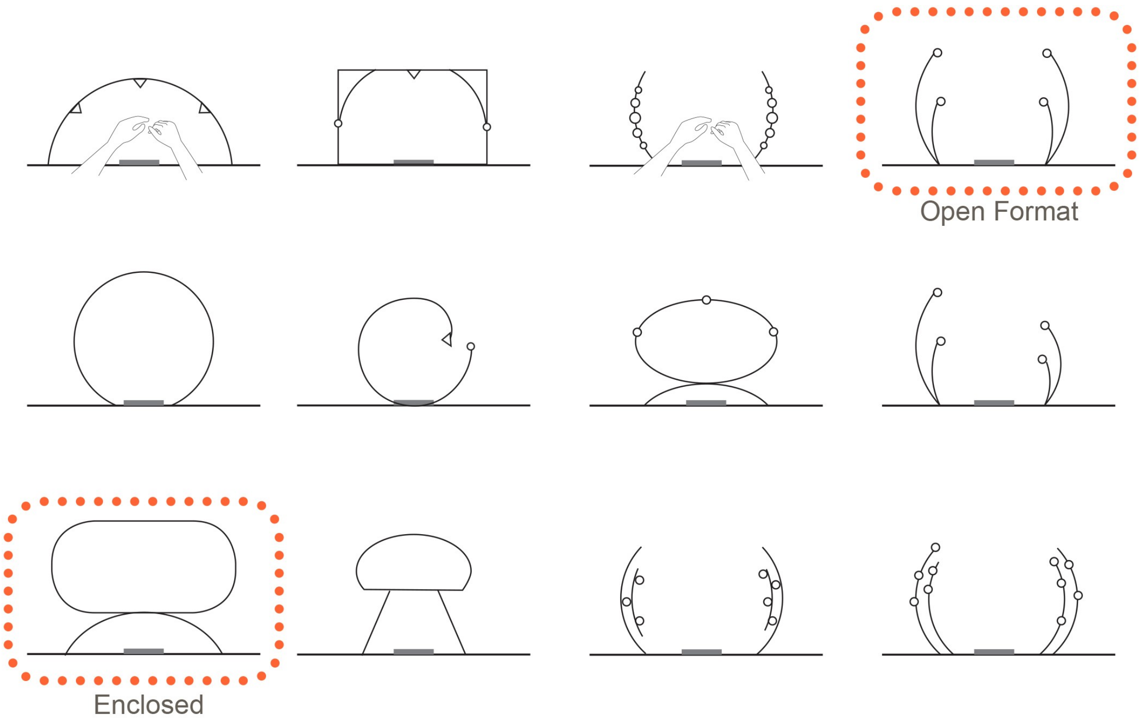

Figure 2: Initial concept sketches (front view) of the hand guide device. These sketches fall into two categories: enclosed hand guides and open format hand guides.

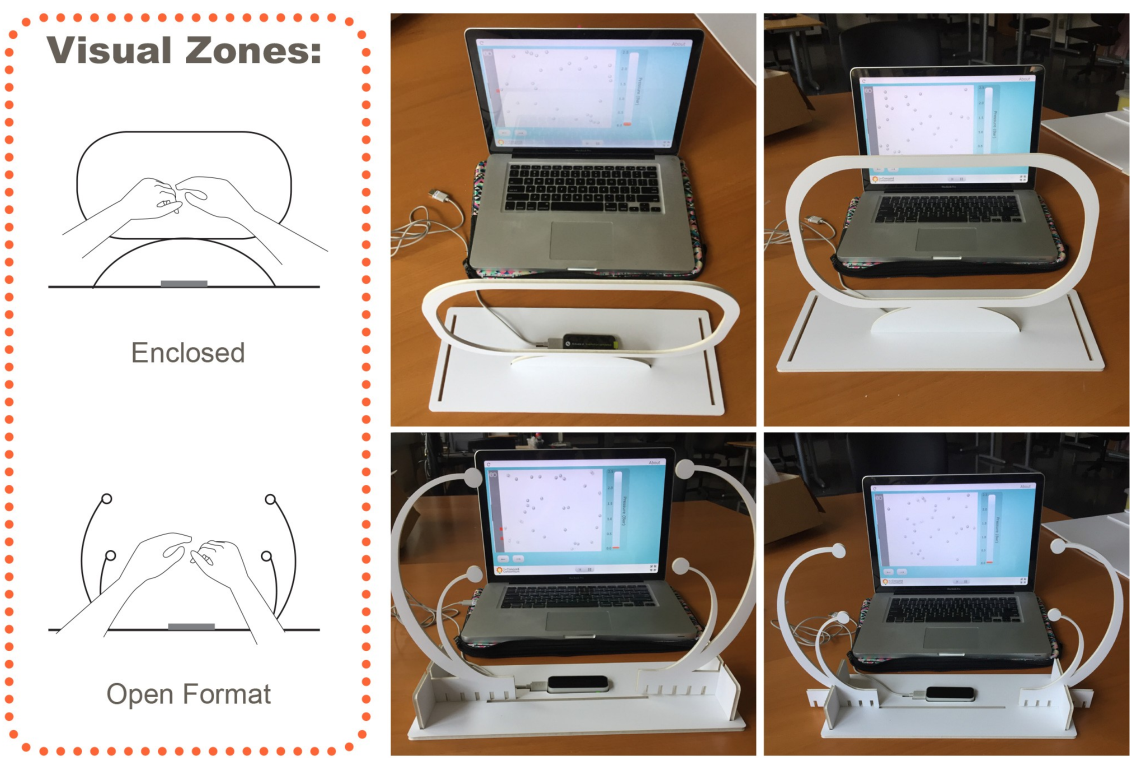

Figure 3: Initial, low fidelity prototypes of an enclosed hand guide and an open format hand guide.

User Testing

GRASP study participants who had the opportunity to engage with the two hand guide devices greatly preferred the open format hand guide (figure 4). One student stated, "I feel like [the open format hand guide] is more useful, because it's a show of where you're supposed to put your hands. Yeah, cause it shows exactly where you're supposed to put your hands for it to operate most efficiently." While the researchers reported that the students engaging with the open format device had successful interactions with the simulation. These reactions may indicate that the device offers an expectation effect, improving overall performance based on the expectation of better performance (Lidwell et. al., 2003, p. 68-69). The implementation of the hand guide device could increase a study participant's confidence engaging with the simulations, leading to an improved outcome.

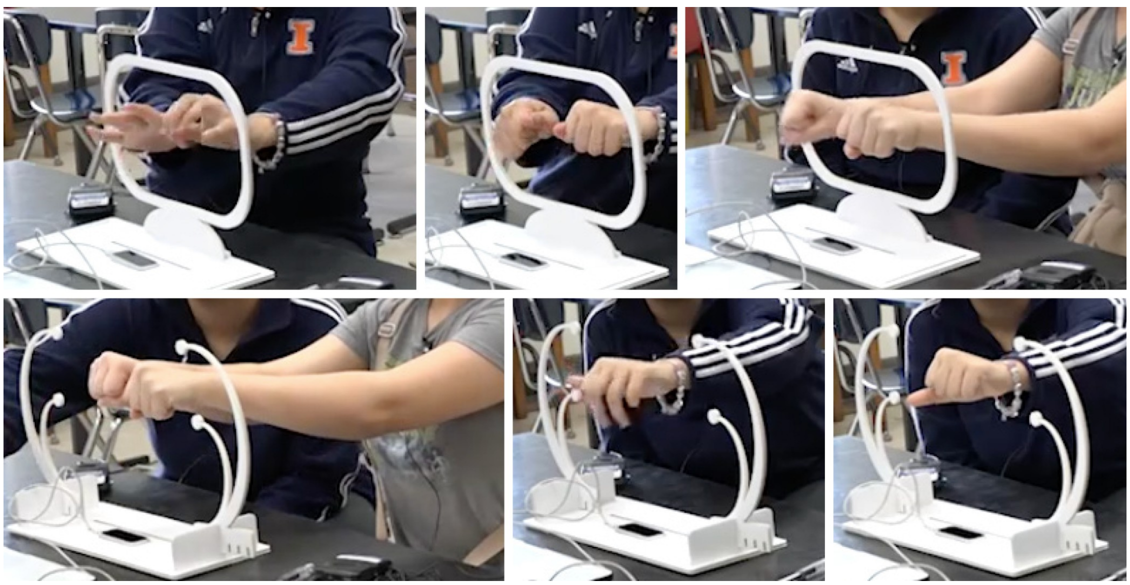

Figure 4: Students working in a dyad interact with the enclosed and open format hand guides. Participants that interacted with the low fidelity models provided feedback on their experience interacting with each hand guide.

Design Iterations and Functionality

After testing with the low fidelity prototypes, it was determined that the design would move forward with the open format hand guide system. A number of design iterations were explored for these guides (figure 5); experimenting with various identifiable features used to visually cue participants, but the research team determined that the initial designed form for the hand guides was preferred as it drew inspiration most directly from the molecules depicted in the simulations. The researchers also identified that the device needs to be very easy to set up, tear down, and transport to and from schools. This feedback guided the design process towards a modular carrying system. Multiple conceptual directions were explored to create a device base that functions as both the support for the adjustable hand guides and a carrying case (figure 6).

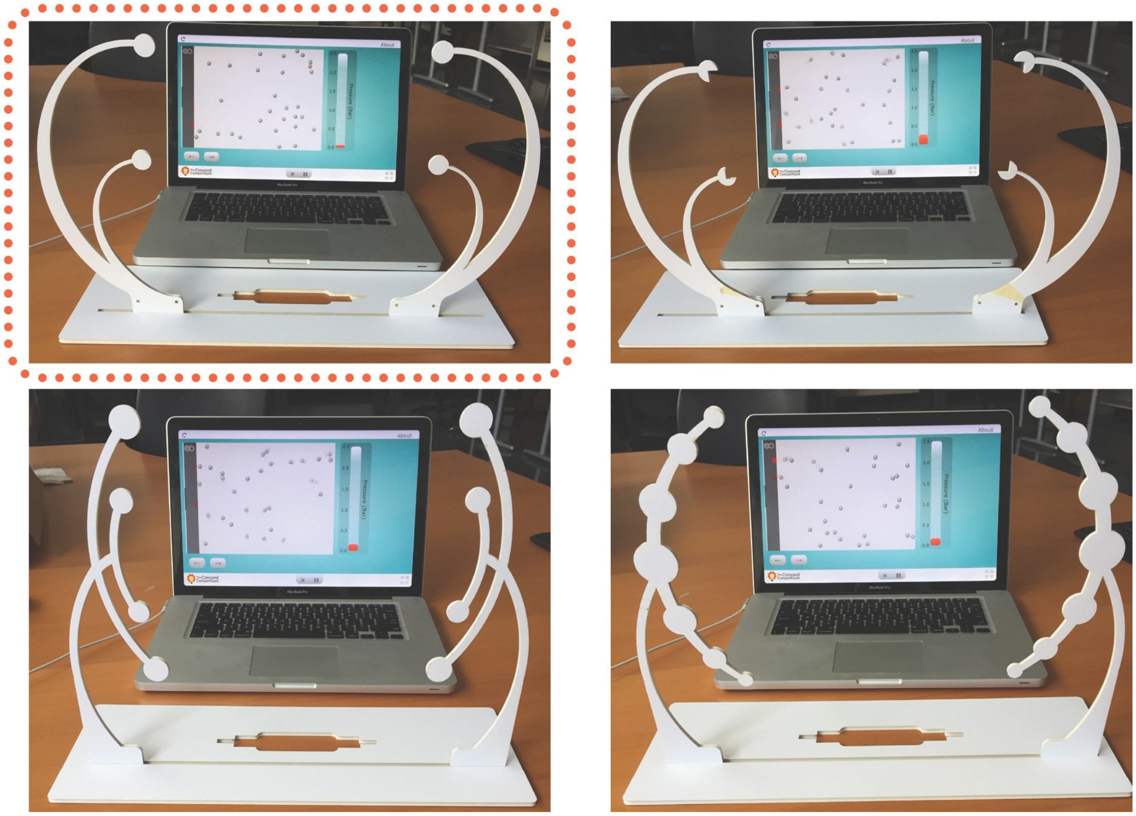

Figure 5: Multiple iterations of the open format hand guide were created. The research team and participants ultimately chose the initial form concept from the available iterations.

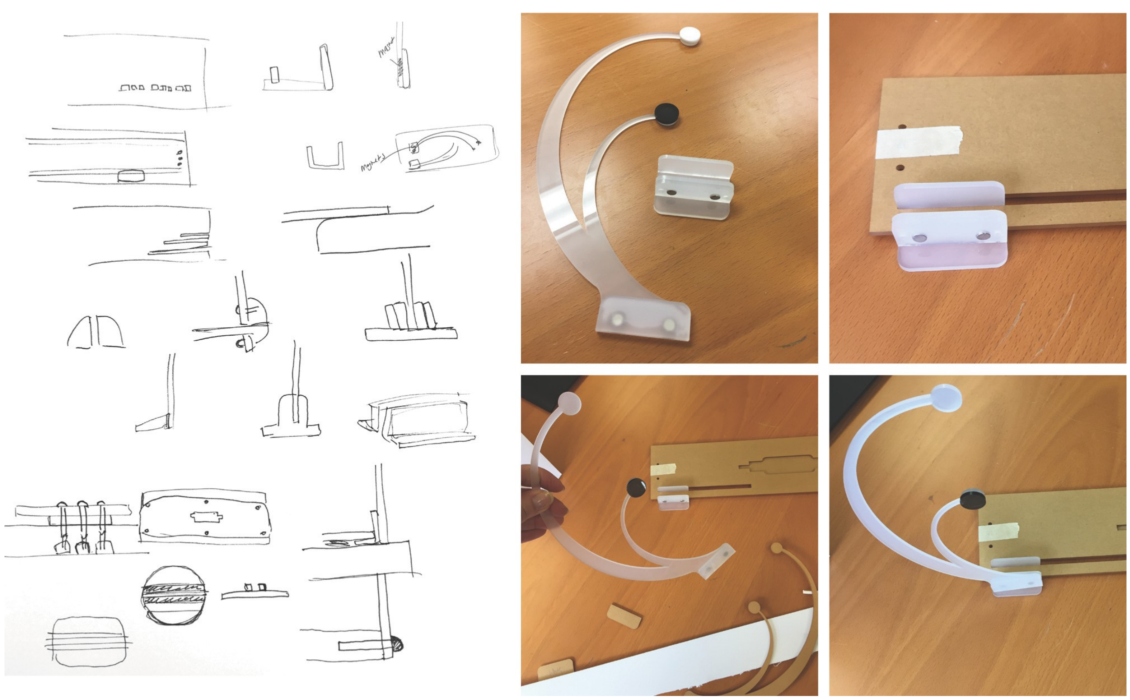

Figure 6: Functionality brainstorming and testing was completed prior to the assembly of the final model.

Findings

The current developed model (figure 7) is constructed out of laser cut acrylic, plywood, magnets, and fasteners. The device can be carried with the detachable hand guides magnetically fastened to the side. When in use, the hand guide pieces magnetically attach to two sleds that can be moved left and right to accommodate for gesture width. The based of the device also features an area for the LEAP motion to rest securely throughout testing.

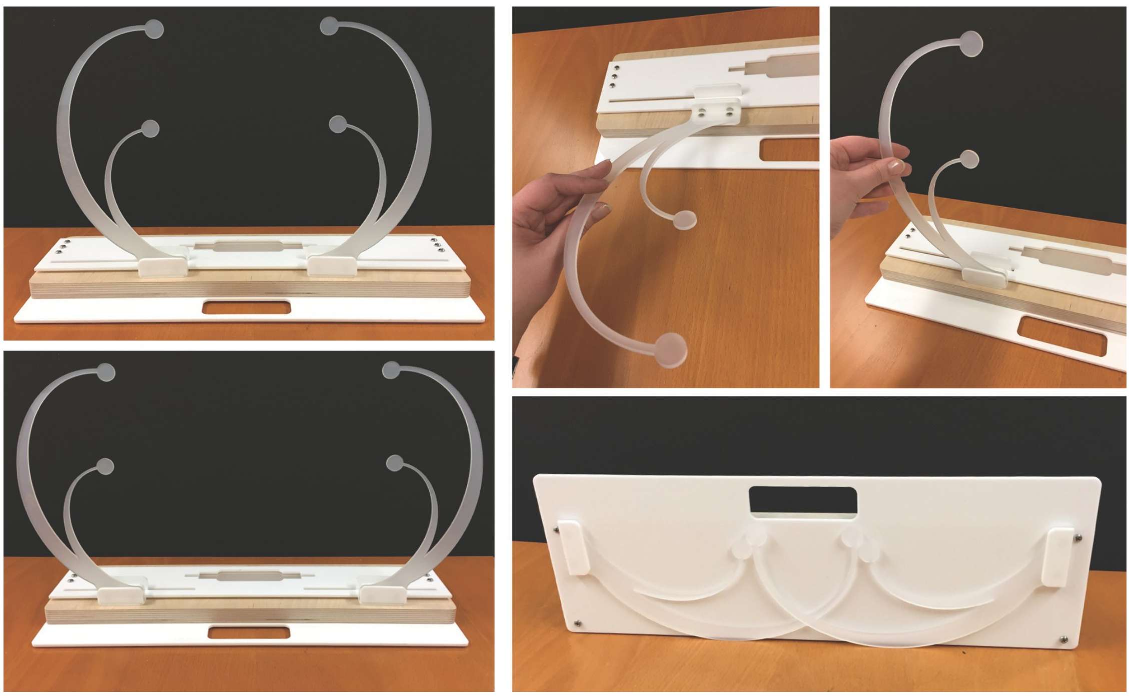

Figure 7: The current hand guide device that is being used for the GRASP study.

Discussion

Researchers have begun use of the current iteration of the hand guide device (figure 8). As the researchers include the hand guide device in their explanation of the science simulation, study set up, and gestural interactions the device has the potential to act as a tool for cognitive offloading. The device gives participants a reference within their visual field of where the researcher indicated that they should complete their gestures throughout their interaction with the simulation. In early use, researchers reported that even having the hand guide device in the room to point at seemed to be advantageous. Further testing needs to be completed to document the impacts of its use and continue shaping further design iterations of this device.

Additional takeaways from initial tests with this model include: the need to reduce the weight of the overall device (primarily caused by the plywood base), eliminate the use of exposed hardware, and create magnetic sleds out of a single material for long term durability. The potential for unique hand guide sets for each simulation is also in consideration. The current design is specifically for the GRASP research project, but could support eventual development for all Leap motion devices.

Figure 8: GRASP researchers using the hand guide device for individual student interviews.

The GRASP research project is ongoing, and the hand guide device has been incorporated into recent and upcoming data collection. As the project moves forward, the research team will continue to complete dyad interviews, utilizing a single computer and leap device, while also beginning to explore applications within a larger classroom context. This shift may lean towards the use of individual tablets for students or could involve augmented reality technology (e.g., Microsoft hololens). The design of future studies will take into account the impact of the hand guide developed throughout the course of this project and potentially incorporate a similar visual cue as part of the simulation interface or augmented reality experience.

Conclusion

The development of this hand guide device provides an example of opportunities that arise from focusing on the design forms and human experience of intentional learning environments, taking into consideration the situated nature of embodied learning. The GRASP research team identified the benefit of taking all aspects of the learning environment into consideration and took action to further diversify the expertise of their team. Each designed form in a material landscape has an impact on the human experience and has the potential to play a crucial role in learning in an educational setting. The initial outcomes of this project bring to light some interesting research questions pertaining to the influence of designed form on gesture, learning, and memory in an educational setting. These emerging questions and research areas act as a reminder of the importance of interdisciplinary engagement, inspiring future collaboration and exploration in order achieve better design outcomes.

Acknowledgments

GRASP is a collaboration between the University of Illinois at Urbana-Champaign and the Concord Consortium. This material is based upon work supported by the National Science Foundation under Grant No. DUE-1432424. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. We would also like to thank the whole GRASP team for their help in testing and giving input on the design work described here.

References

Barsalou, L. W. (2008). Grounded Cognition. *Annual Review of Psychology Annu. Rev. Psychol., 59(1)*, 617-645.

Clark, A. (1997). *Being there: Putting brain, body, and world together again*. Cambridge, MA: MIT Press.

Davis, M. (2012). *Graphic design theory*. London: Thames & Hudson.

Ellis, W. D. (Ed.). (1999). *A Source Book of Gestalt Psychology* (Vol. 2). London: Routledge & Kegan Paul.

Gibson, J. J. (1979). *Ecological approach to visual perception*. Boston, MA: Houghton

Mifflin. Goldin-Meadow, S. (2011). Learning through gesture. *Wiley Interdisciplinary*

Reviews:
Cognitive Science WIREs Cogn Sci, 2(6), 595-607.

Johnson, M. (1987). *The body in the mind: The bodily basis of meaning, imagination, and reason*. Chicago: University of Chicago Press.

Kelley, T., & Littman, J. (2001). *The art of innovation: lessons in creativity from IDEO, Americas leading design firm.* New York City: Currency/Double Day.

Lidwell, W., Holden, K., & Butler, J. (2003). *Universal principles of design: 100 ways to enhance usability, influence perception, increase appeal, make better design decisions, and teach through design*. Beverly, MA: Rockport.

Mcdonagh, D., Bruseberg, A., & Haslam, C. (2002). Visual product evaluation: exploring users' emotional relationships with products. *Applied Ergonomics, 33(3)*, 231-240. doi:10.1016/s0003-6870(02)00008-

Pea, R. D. (1992). *Practices of distributed intelligence and designs for education*. Evanston, Il.: Northwestern University.

Vecera, S. P., Vogel, E. K., & Woodman, G. F. (2002). Lower region: A new cue for figure-ground segregation. *Journal of Experimental Psychology: General, 131(2),* 194-205. doi:10.1037/e537102012-758

Wallon, R. C., & Lindgren, R. (2017). Considerations for the Design of Gesture-Augmented Learning Environments. *Learning, Design, and Technology*, 1-21. doi:10.1007/978-3- 319-17727-4_75-1

Wilson, M. (2002). *Six views of embodied cognition. Psychonomic Bulletin & Review, 9(4)*, 625- 636.

Author Biography

Amanda Henderson

Amanda Henderson is a design researcher with a background in industrial, scenic, and exhibit design. After completing her undergraduate degree in Industrial Design at Carnegie Mellon University, with a minor in Photography, she spent five years in the exhibit design industry. This experience inspired a curiosity to pursue her research focus: how designed forms change human perception of a spatial environment; with the ultimate goal of creating spaces that allow people to feel comfortable and knowledgeable interacting with their surroundings. She is currently pursuing her MFA in Industrial Design at the University of Illinois (Urbana-Champaign); where she is an Instructor of Record at the School of Art & Design and Designer in Residence at the Beckman Institute for Advanced Science and Technology.

Robb Lindgren

Robb Lindgren is a learning scientist and educational technology designer in the College of Education at the University of Illinois at Urbana-Champaign. He is currently an Associate Professor in Curriculum & Instruction and Educational Psychology. His research examines theories and designs for learning within emerging media platforms (e.g., simulations, virtual environments, mobile devices, video games, augmented and mixed reality, etc.). He seeks to understand how digital technologies can be used to construct new identities and generate new perspectives that lead to stronger comprehension of complex ideas, particularly in STEM content areas. His work investigates how physical, body-based interactions with learning content can facilitate new understandings, and how games and simulations can be effectively designed to take these types of interactions as input.