Mixed Reality that Brings Science Concepts to Life

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In his *Critique of Pure Reason*, the Enlightenment philosopher Immanuel Kant asserted that "conception without perception is empty, perception without conception is blind… The understanding can intuit nothing, the senses can think nothing. Only through their union can knowledge arise." More than 200 years later, his wisdom is still enlightening our work on mixed-reality science experiments.

Mixed reality refers to the integration of real and virtual worlds to create new environments where physical and digital objects co-exist and interact in real time to provide user experiences that are impossible in either real or virtual world alone. Perception is a cognitive process that occurs in the real world, whereas conception is a cognitive process that can be stimulated by virtual reality. What about coupling the two processes using mixed reality?

Enacting Science Concepts in the Real World

One way to look at the cognitive potential of mixed reality is to start with learning in hands-on activities. Students like hands-on activities because they provide perceptual experiences that feel physically relevant to them. For these experiences to make sense to students, however, they must be prepared with the conceptual frameworks needed to understand what they perceive. For example, while conducting an experiment about a gas law, students must be able to reason the results with the kinetic theory (that a gas is made of many interacting molecules in perpetual random motion). In this case, the temperature, pressure, and volume of a gas can be perceived, whereas molecules, their motions, and their collisions cannot—they are, in fact, concepts scientists developed to comprehend perceivable properties of gases.

Traditionally, students learn the kinetic theory first and then investigate gas laws in the lab. But no integrated learning is guaranteed. Even if students have studied a concept and performed well in a written exam, they can still fall back on their possibly erroneous preconceptions in a lab activity, as if they had not been taught about it before.

How can we enhance conceptual learning in lab activities? Compared with Kant's time, today we are privileged to have powerful computers for rendering abstract concepts as visual, dynamic interactives through computation. Using sensors, such computer simulations can be seamlessly integrated with perceptual experiences in the real world (Figure 1). One of the approaches with which we are experimenting is to use a tablet to create a visualization that is dynamically driven by sensor-detected changes of physical properties caused by the motion or action of the holder. In this way, **science concepts can be "naturally" inserted into student explorations and enacted in the real world**. For example, students can move a tablet that runs a molecular simulation of air around a building to experience how the air temperature they feel is related to the simulated motion of air molecules shown on the screen; the tablet can run a simulation revealing how water molecules form a regular lattice structure when the environmental temperature is below the freezing point and how the lattice breaks when the tablet is moved to a warm room.

Incorporating student action as a degree of freedom, these mixed-reality activities represent a novel method to blend computer simulations into the real world: Simulations capable of reacting to the changes in the environment can expand the scope of student activities to a larger physical space where gradients of physical properties exist. Moving through such a space with a mobile simulation that interprets numeric sensor data with visualized conceptual pictures provides a new way for students to discover the science concepts in action. Given the growing popularity of mobile educational platforms such as smartphones and tablets, this kind of mixed-reality application will become even more practical and pervasive in the future.

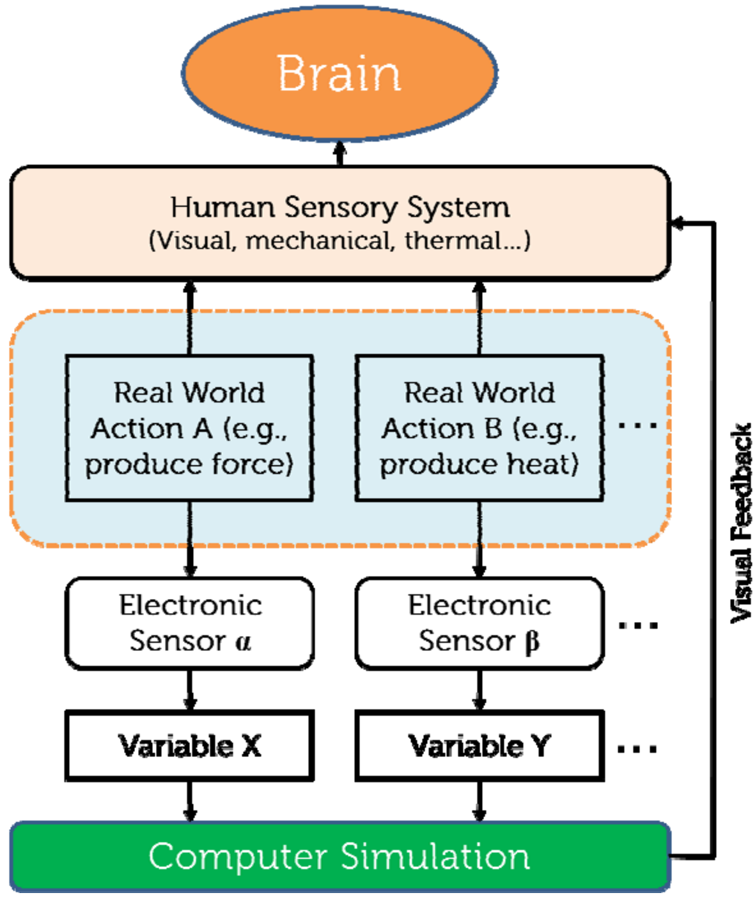

Figure 1: Mixed-reality labs use sensors and simulations to create integrated multisensory learning experiences. Real-world actions result in changes that are simultaneously perceived by both the user and the sensors. Without any delay, the sensors signal the simulation to update the display accordingly, providing instant visual feedback that enhances perception.

Situating Computer Simulations with Perceptual Anchors

The other way to look at the cognitive potential of mixed reality is to start with learning in computer simulations. Simulations of invisible properties and processes are now widely used to teach science concepts. However, visual simulations of unseen phenomena alone are often insufficient for learning, because cognition requires a real-world context. For conceptual understanding to take root, students must find ways to connect new concepts to their perceptual experiences and integrate them with their current knowledge.

To help students make these mental connections, instructional designers often contextualize science animations with graphics that represents familiar objects. For example, clicking an image of a bike pump in a gas simulation will add molecules; clicking an image of a Bunsen burner will add heat; and so on. These images serve as the *perceptual anchors* that link the exotic picture of random motion of molecules to everyday experiences about pressure and temperature. These anchors, however, are limited to only visual perception.

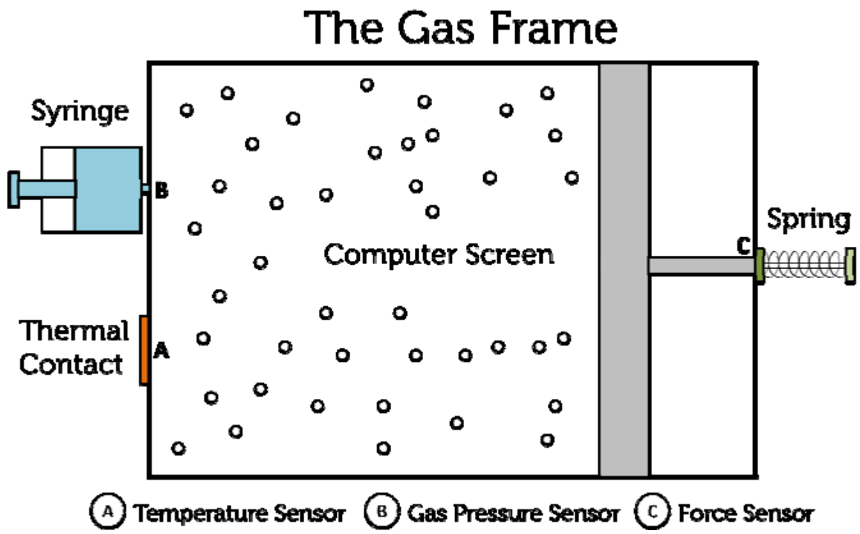

Figure 2: A mixed-reality activity for studying gas laws based on our Frame technology, in which students can "push" or "pull" a virtual piston using their hands, "heat" or "cool" virtual molecules using a hot or cold object, and "inject" or "draw" virtual molecules using a syringe.

What if, instead of clicking on some images, students can actually exert force or add heat to "naturally" compress or heat a simulated gas (Figure 2)? This way, the strange simulation can be meaningfully situated in a familiar environment and connected with different kinds of perception (e.g., spatial, mechanical, and thermal senses). In this mixed-reality configuration, **natural user actions are mapped to variables in the simulation to create an illusion as if students could physically manipulate the virtual molecules at an extremely small scale**.

Students can even "feel" interatomic forces using mixed reality. Figure 3 shows an activity that connects the sense of force with a visualization of interatomic interaction. Students can investigate the interatomic force as a function

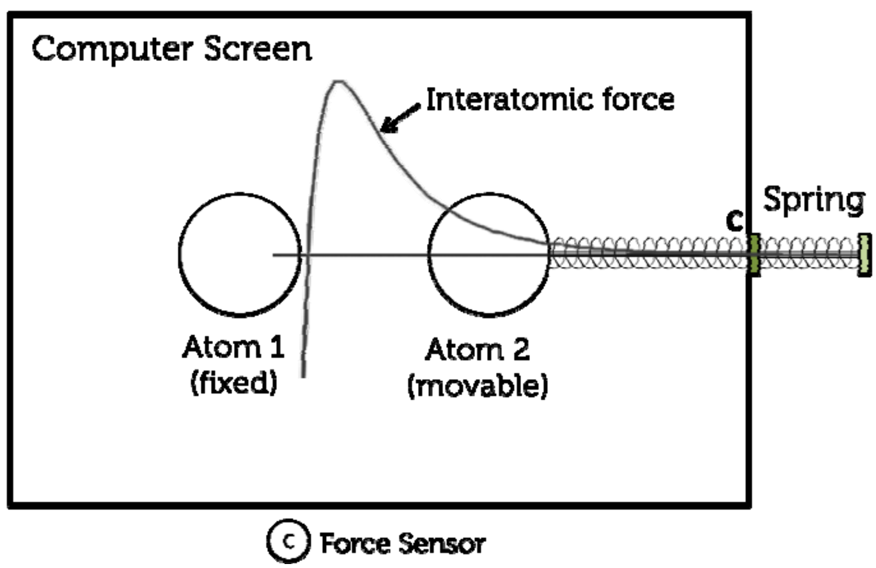

Figure 3: A mixed-reality activity for studying interatomic interactions. Students can push or pull a spring to "feel" the attraction and repulsion force between two atoms.

of the distance between two atoms. For example, they will find that, when the atoms start to overlap, they will not get closer no matter how hard they push the spring; the attraction force is the greatest at a certain distance but quickly diminishes when the atoms are further apart. With their hands, they discover the van der Waals force. This activity can be extended to teach other atomic-scale interactions, such as ionic bonds, covalent bonds, hydrogen bonds, and protein-ligand docking.

Collaborating on Inquiry

Mixed-reality labs can use multiple sensors to activate and enhance multisensory perception in science simulations. Interactions with the sensors can come from multiple students. This allows a group of students to manipulate a simulation jointly using multiple inputs. For example, one student exerts force to compress or decompress a virtual gas while another uses a hot or cold object to change its temperature and together they investigate Gay-Lussac's law (i.e., the pressure of a gas is proportional to its temperature). Imagine two students each control the temperature of a virtual gas in a compartment separated from the other through a piston and together they discover Charles's law (i.e., the volume of a gas is proportional to its temperature); imagine they each control the number of a virtual gas in a similar two-compartment setup and together they discover Avogadro's law (i.e., the volume of a gas is proportional to its molecule count). **This kind of mixed reality enables students to physically play the roles of different science concepts and learn their relationships collaboratively**.

Concluding Remarks

Uniting the actions of students in the real world and the reactions of the molecules in the virtual world, mixed reality provides an unprecedented way to learn a set of important concepts in physical science. If Kant could be brought back through a time machine, he would probably be pleased to see that there is now a technology to promote the union of perception and conception.

Link

http://energy.concord.org/mrl