# Mixed Reality

## Brings Science Concepts to Life

*By Charles Xie*

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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 in mixed-reality science experiments.

Mixed reality refers to the integration of real and virtual worlds to create new environments where physical and digital objects coexist and interact in real time to provide user experiences that are impossible in either the real or virtual world alone. Perception is a cognitive process that occurs in the real world while conception is a cognitive process that can be stimulated by virtual reality. Mixed reality couples the two processes.

### Enacting science concepts in the real world

One way to look at the cognitive potential of mixed reality is to start by examining hands-on activities. Students enjoy hands-on activities because they provide perceptual experiences that feel real. For these experiences to make sense, however, students must be prepared with the conceptual framework needed to understand what they perceive. For example, while conducting an experiment about a gas law, students must be able to reason about the results using the kinetic theory (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, while molecules, their motions and their collisions cannot—these are concepts scientists developed to explain the perceivable properties of gases.

Traditionally, students learn the kinetic theory first and then investigate gas laws in the lab. But integrated learning is not guaranteed. Even if students have studied a concept and performed well on a written test, they can still fall back on their possibly erroneous preconceptions in a lab, as if they had not been taught the concept earlier.

To enhance conceptual learning in lab activities, we can use powerful computers to render abstract concepts as visual, dynamic simulations and use sensors to seamlessly integrate the simulations with perceptual experiences in the real world (Figure 1). Such simulations can respond to changes of physical properties caused by the user's actions. In this way, students can see the science concepts at work in the real world. For example, students can walk around a building holding a tablet that is running a molecular simulation of air and experience how the air temperature they feel is related to the simulated motion of air molecules displayed on the screen. And when a student ventures outside, the tablet can run a simulation revealing how water molecules form a regular lattice structure when the environmental temperature is below the freezing point; that lattice would break when the student walks back inside.

These mixed-reality activities represent a novel method of blending computer simulations into the real world. Simulations capable of reacting to changes in the environment provide a way to translate the otherwise obscure numeric data from sensors into compelling visualizations of science concepts.

### Situating computer simulations with perceptual anchors

Another way to look at the cognitive potential of mixed reality is to start with learning with computer simulations. Simulations of invisible properties and processes are now widely used to teach science concepts. However, visual simulations of invisible 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 represent familiar objects. For example, clicking an image of a bike pump in a gas simulation adds molecules; clicking an image of a Bunsen burner adds heat, and so on. These images serve as the *perceptual anchors* that link the picture of random molecular motion to the everyday experiences of pressure and temperature. These anchors, however, are limited to visual perception.

What if, instead of clicking on images, students could actually exert force or add heat to 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

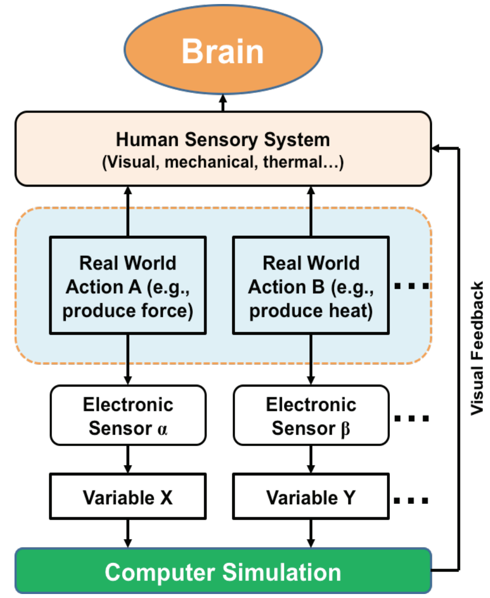


**Figure 1:** Mixed-reality labs use sensors and simulations to create integrated multisensory learning experiences. Real-world actions result in changes that are simultaneously perceived by both the user and the sensors. Without any delay, the sensors signal the simulation to update the display accordingly,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

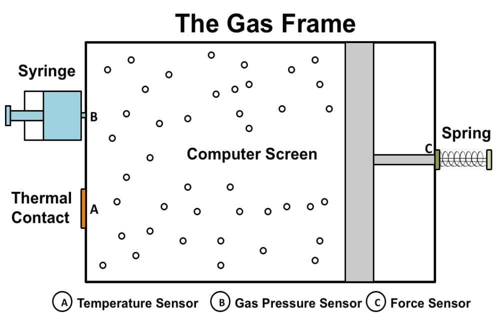


**Figure 2:** A mixed-reality activity for studying gas laws based on our Frame technology, in which students can "push" or "pull" a virtual piston using their hands, "heat" or "cool" virtual molecules using a hot or cold object and "inject" or "draw" virtual molecules using a syringe.

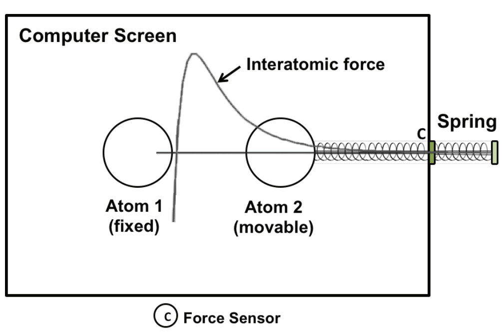


**Figure 3:** A mixed-reality activity for studying interatomic interactions. Students can push or pulla spring to "feel" the attraction and repulsion force between two atoms.

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 of the distance between two atoms. They will find that, when the atoms start to overlap, they do not get closer no matter how hard the student pushes the spring, and the attraction force is the greatest at a certain distance but quickly diminishes when the atoms are further apart. In this way, students will 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 multimodal perception in science simulations. 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. Together, they investigate Gay-Lussac's law (the pressure of a gas is proportional to its temperature). Or imagine two students each controlling the temperature or number of molecules of a virtual gas in a compartment separated from the other by a piston. They would discover Charles's law (the volume of a gas is proportional to its temperature) or Avogadro's law (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.

## Next-generation educational technology

The use of computer simulations across science is emphasized in the Next Generation Science Standards (NGSS). Uniting student actions in the real world with the reactions of simulated molecules, mixed reality provides an unprecedented way to interact with science simulations. It represents an important direction of next-generation educational technology that promises to support NGSS.

**LINKS**

Mixed-Reality Labs
http://mrl.concord.org

# Framing
## Mixed-Reality Labs

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**Laboratory experiences are indisputably a fundamental part of science education. In order to understand the concepts at work in an experiment, students must place the data they collect into a conceptual framework. However, there is often a wide gap between the raw data and the abstract concepts under investigation. For example, to understand heat transfer measured by a thermometer, students must imagine the invisible flow of thermal energy; to understand the intensities measured by an electromagnetic field sensor, they must visualize an electromagnetic field. In these cases, "heat" and "field" are the conceptual frameworks. A lab would have limited educational value if it could not bridge data and the underlying concepts.**

The Mixed-Reality Labs Project funded by the National Science Foundation has set out to develop cyberlearning technologies that promise to narrow the gap for students between data and concepts. Our key strategy is to seamlessly combine the visualization power of simulations and the investigation power of sensors to enhance the learner's perception of reality. Simultaneously supporting inquiries in both the virtual and physical worlds, this integrated approach transcends the limitations of real labs while retaining their tangibility to make learning physically relevant to students.

### Frame technology

We have recently invented a unique technology to realize a large class of mixed-reality labs. The Frame technology is based on the fact that the frame of a computer screen *is* the natural boundary between the virtual world and the physical world and is, therefore, an intuitive user interface for certain human-computer interactions. Compared with other interfaces, the Frame allows users to interact with the computer from the edges of the screen (Figure 1).

In our vision, the Frame is an adjustable structure that can "frame" several kinds of display screens (hence the name). A variety of sensors can be plugged into slots on the Frame. Each sensor slot registers a port number so that the computer knows from which direction the signal comes. If sensors are wirelessly connected to a mobile computer, the entire system becomes portable.

By running a simulation in full screen mode, the data from sensors on the Frame looks as though it's "transmitted" into the simulated scene in real time. For example, moving a hot object close to the Frame where there are temperature sensors creates an input to an ongoing heat transfer simulation, which then produces a visual effect *as if* heat could flow into the screen from the hot object. Similarly, directing a light beam onto light sensors on the Frame can create a scenario *as if* light could shine into a virtual world to warm up a solar house or start photosynthesis in a leaf.

The Frame technology follows the typical way we conduct real experiments, namely, by allowing students to change variables in a system and observe how it responds to those changes. Unlike a real experiment, however, the inputs are applied to change a virtual system. Unlike a virtual experiment, the inputs come from the real world. Bridging the two worlds, the Frame takes advantage of learning opportunities in both worlds.

### Three types of frames

The Frame is a flexible technology because many different displays can be "framed," as the following illustrations demonstrate.

#### Detector

The Detector Frame converts a tablet computer into a mobile device that can detect changes in the real world and augment the signals with virtual reality. For instance, when a "framed" tablet approaches a heat source, it will show a flow of thermal energy on the screen as if the screen were thermally sensitive (Figure 2). In this case, the

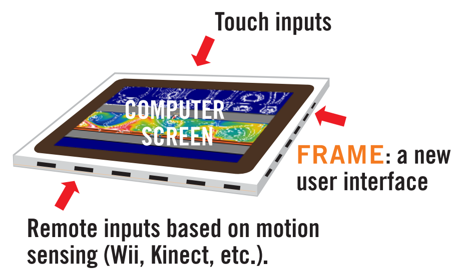


**Figure 1.** Interacting from the edges.

Detector translates obscure raw data into a more understandable and visually appealing picture using computer visualizations. Compared to showing numbers or graphs of data from the sensors, this mixed-reality lab extrapolates the data to the virtual world to provide the contextualization necessary to understand their meaning.

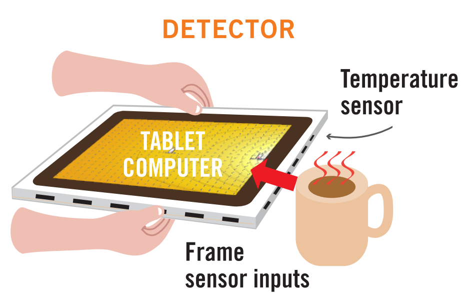


**Figure 2.** Mixed-reality thermal imaging

#### Workbench

The Workbench Frame converts the flat LCD display of a computer into an experiment station. A mixed-reality wind tunnel with one or more anemometers measures the intensity of air streams as the student

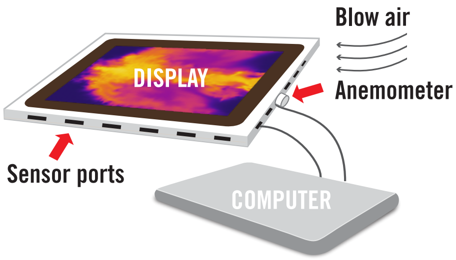


**Figure 3.** A mixed-reality wind tunnel.

blows and creates inputs to a running computational fluid dynamics (CFD) simulation visualized on the screen (Figure 3). This lab can teach forced convection, wind turbines, airfoils, and more. Students can explore relationships between real air speed data and virtual flow patterns (e.g., streamlines, vortices, or turbulences).

## Projector

The Projector Frame turns a projector screen into a magnified lab on the wall. Sensor bars are mounted on the wall to "frame" the projection area. Figure 4 shows a mixed-reality atomic microscope projected onto a screen. Temperature and force sensors translate students' actions on the sensor bars into signals that are then used to adjust variables such as temperature and pressure. In the gas simulation shown in Figure 4, a student can push the piston to compress the gas by exerting a force on the sensor bar. Another student can heat up or cool down the gas by moving a hot or cold source to where the temperature sensor is located. The actions of these two students can be performed at the same time, creating an interaction between them mediated by the simulation. For example, while one student is compressing the gas, another student can simultaneously explore how much she should heat up the gas in order to push the piston back, which leads to understanding the Ideal Gas Law in a collaborative setting.

## Looking ahead

In purely virtual experiments, students interact with simulations through clicking or touching widgets on the screen that represent physical variables. Mixed-reality experiments replace these graphical widgets with multisensory inputs (such as light, heat, or pressure) that are semantically integrated with virtual and physical elements. This technology could help students build stronger mental associations of perceived facts and visualized concepts.

Mixed-reality applications depend on sensors to detect the changes caused by users or the environment. Although sensors are now an important and ubiquitous part of smartphones and tablets, the number and types of sensors supported by those devices are—and will continue to be—limited. Manufacturers are unlikely to include all the sensors on the wish list of science education. But imagine a future when you can buy "frames" or cases for your computers that will have customized sensors. Our Mixed-Reality Labs is paving the road for that future.

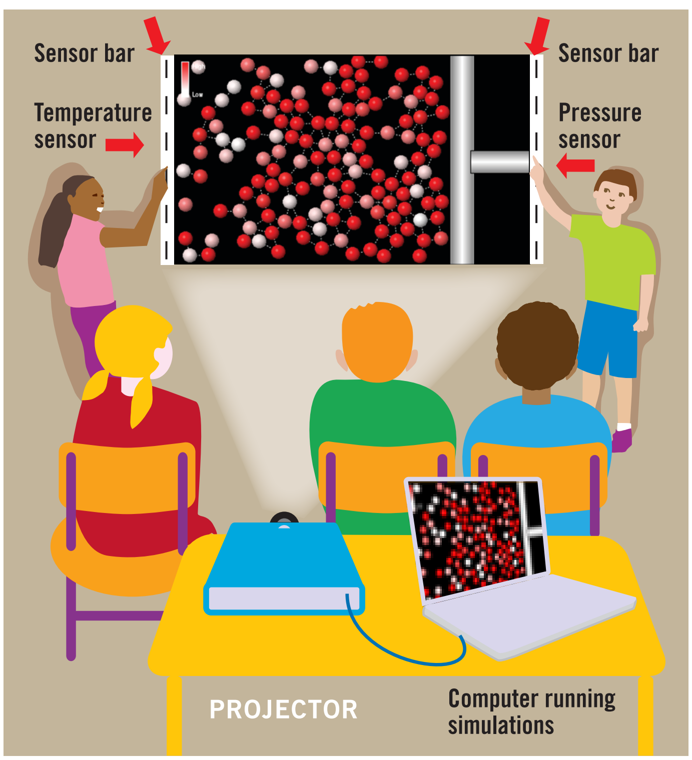


**Figure 4.** A mixed-reality atomic microscope.

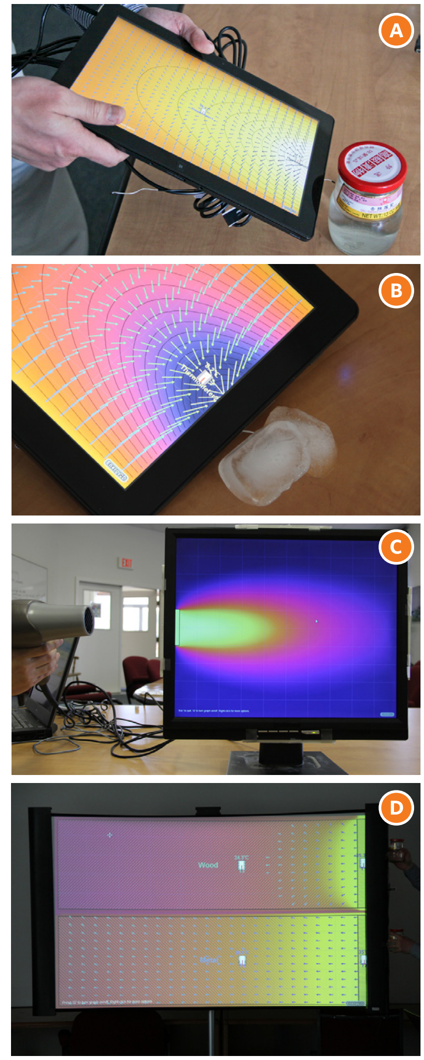


**Figure 5.** Frame prototypes built around our Energy2D simulator. (a) A tablet "Thermal Imager" near a jar of hot water. (b) A tablet "Thermal Imager" near ice cubes. (c) An LCD display as a "Thermal Imager" showing the forced convection by a hairdryer. (d) A projector screen as a "Thermal Imaging Wall" heated by two jars of hot water at the right edges of two areas representing materials of different thermal conductivities.

**DEMOS**

Watch videos of the Frame at: http://energy.concord.org/energy2d/e2dmr1.html.