Making Energy Easy: Interacting with the Forces Underlying Chemical Bonding Using the ELI-Chem Simulation

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Introduction

This study seeks to develop and explore high-school chemistry students' conceptual understanding regarding forces and energy involved in chemical bonding. Having no access to the molecular world and lacking the force-based explanation of chemical bonding, students rely on incorrect interpretations and intuitive heuristics, such as the 'octet-rule', i.e. eight electrons in the outer energy level (Taber, 2002). Most of them view chemical bonds incorrectly as attached solid spheres for which energy is needed to bring them together, or as coiled springs that release energy when relaxed (Boo, 1998).

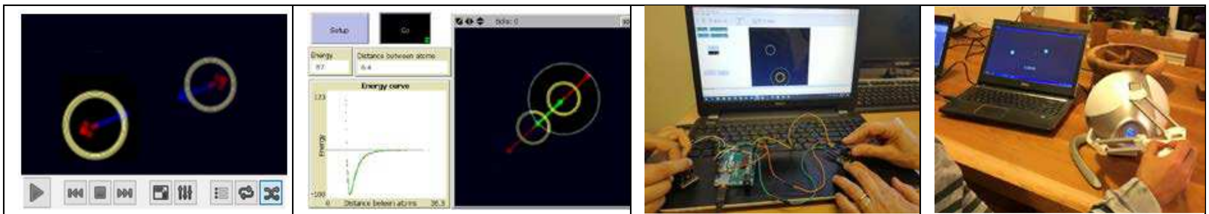
We designed and developed an Embodied Learning Interactive environment - ELI-Chem, to alleviate these difficulties: (1) ELI-Chem removes the abstraction by providing bodily experience with the molecular level as proposed by embodied learning theory (Barsalou, 1999); and (2) ELI-Chem is based on a mathematical simulation of attraction-repulsion forces between atoms, supporting a force-based teaching approach (Nahum-Levy et al., 2007; Taber, 2002).

The working hypothesis is that more intense (in terms of force and distance moved) physical experience with the underlying electrical forces provides a stronger foundation for understanding energy changes during chemical bonding, and related concepts such as chemical stability or bond strength.

The learning environment

The base of the learning environment is a chemical bonding computer simulation displaying the attractive and repulsive forces between two atoms and the resulted potential-energy diagram. Using a mouse, students interact as an atom with another atom, exploring changes of forces and energy.

The users' interactions as an atom within the system were varied in the required motions, in terms of the distance along which the hand moves and the force necessary to move the atom. By connecting a joy-stick and a haptic device to the simulation, the ELI-Chem system offers sensory-motor experiences of the attractive and repulsive forces at four increasing degrees of embodiment (Figure 1): (1) *observing videos* that involve no action; (2) *using a mouse* to move an atom in the simulation; (3) *using a joy-stick* that moves a greater distance than the mouse, but similar force; and (4) *using a haptic device* with which motion takes place at a greater distance and greater force than the other devices.



(a) (b) (c) (d)

Figure 1. ELI-Chem degrees of embodiment. (a) No motion (video), (b) mouse interaction, (c) Joy-stick interaction and (d) Haptic device.

Methods

A DBR-mixed methods approach was used. Participants were high-school students majoring in chemistry. Study 1 focused on forces (N=23). Study 2 focused on energy (N=6). The Main Study included four conditions: video, mouse, joy-stick and haptic device with identical activities (N=48). Multiple-choice questionnaires, interview protocols, worksheets and screen-capture of their activities were used to generate the corpus of data. All studies had a pretest-intervention-posttest design, with the Main Study including four parallel groups.

Findings

We present the results of study 1 and study 2 that we conducted with students using a mouse (the base of the learning environment), followed by the results of the Main Study - the four degrees of embodiment.

Simulation-based reasoning with mouse interaction

Study 1: *Forces* involved in chemical bonding. Students were asked to describe chemical bond, why it is formed and what a stable bond means. Findings show that before the intervention, students did not consider repulsion forces when reasoning about the chemical bond, leading to an incorrect mental model of static "touching" balls. Learning with the ELI-Chem simulation helped students shift to consider the role of repulsion forces and perceive the chemical bond as a dynamic balance between attractive and repulsive forces.

Study 2: *Energy* involved in chemical bonding. Students were asked to describe the energy changes during bonding. Findings show that before the intervention students did not refer to forces when asked about energy; their responses were confused and inconsistent. In the post-interviews however, they described the correct energy changes using the force-base explanation.

Simulation-based reasoning with increasing degrees of embodiment

In both pre- and post-questionnaires students were asked about forces and energy involved in chemical bonding; questions were based on interviews and questionnaires of study 1 and study 2. Findings show that there was an increase in students' conceptual understanding in all four groups. Three groups - video, mouse and joystick - were indistinguishable in their learning effects. Using the haptic device showed nearly double learning gain.

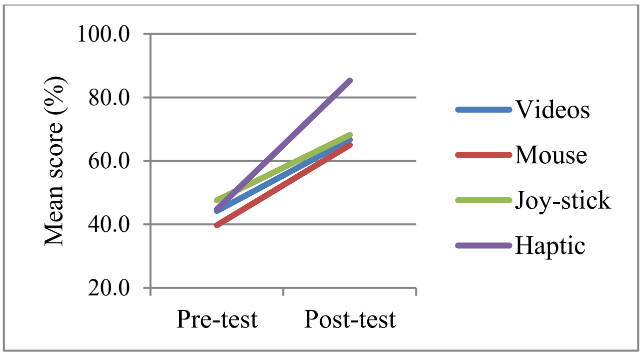


Figure 2. Change in students' understanding of conceptual knowledge.

Conclusions

Learning with the ELI-Chem environment provided students the vocabulary, concepts, principles and analogical sensorimotor schemes that are required to shift from an octet-based explanation to a force-based explanation. From inconsistency and rote articulations students moved to coherent explanation-based reasoning. They explained chemical stability as a dynamic balance between attraction and repulsion forces, they described correctly that bond formation is due to attraction forces and is associated with release of energy, and that bond breaking requires energy in order to overcome the balance between attraction and repulsion forces. Adding haptic information to create a multimodal experience of chemical bonding resulted with increased learning gain, indicating on the use of sensorimotor schemes in the building of a more accurate mental models and representations. Having the words, sensorimotor schemes, and powerful tools for explanatory force-based reasoning, students constructed a more scientific understanding of the forces and energy that are involved in chemical bonding.

References

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Acknowledgements

This research was supported by the Ministry of Science, Technology and Space, Israel.