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The effects of augmented virtual science laboratories on middle school students' understanding of gas properties

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ABSTRACT

The Next Generation Science Standards (NGSS) emphasize authentic scientific practices such as developing models and constructing explanations of phenomena. However, research documents how students struggle to explain observable phenomena with molecular-level behaviors with current classroom experiences. For example, physical laboratory experiences in science enable students to interact with observable scientific phenomena, but students often fail to make connections to underlying molecular-level behaviors. Virtual laboratory experiences and computer-based visualizations enable students to interact with unobservable scientific concepts, but students can have difficulties connecting to actual instantiations of the observed phenomenon. This paper investigates how combining physical and virtual experiences into augmented virtual science laboratories can help students build upon intuitive ideas and develop molecular-level explanations of macroscopic phenomena. Specifically, this study uses the *Frame*, a sensor-augmented virtual lab that uses sensors as physical inputs to control scientific simulations. Eighth-grade students ($N = 45$) engaged in a Frame lab focused on the properties of gas. Results demonstrate that students using the Frame lab made progress developing molecular-level explanations of gas behavior and refining alternative and partial ideas into normative ideas about gases. This study offers insights for how augmented virtual labs can be designed to enhance science learning and encourage scientific practices as called for in the NGSS.

1. Introduction

The Next Generation Science Standards (NGSS) stress authentic scientific practices such as developing models and constructing explanations of phenomena (NGSS Lead States, 2013). However, research documents that students have difficulty developing molecular-level explanations of observable phenomena, critical to complex science understanding (Ben-Zvi, Eylon, & Silberstein, 1986; Gabel, 1999). Moreover, existing approaches to science classes can leave students with isolated or superficial ideas (Linn & Eylon, 2011). For example, hands-on laboratory experiences give students direct experience with phenomena and scientific practices (National Research Council [NRC], 2006), but are not always successful in getting students to understand underlying scientific concepts (Finkelstein et al., 2005). Virtual technology tools, software, and simulations, have been successfully implemented in science classrooms to help students develop explanations of complex science topics (Bell & Trundle, 2008; Carlsen & Andre, 1992; Chiu & Linn, 2014; Höffler & Leutner, 2007; Honey & Hilton, 2011; Jaakkola, Nurmi, & Veermans, 2011; Windschitl & Andre, 1998). However, research also demonstrates how students using visualizations can focus on superficial aspects (Lowe, 2004), overestimate their understanding (Chiu & Linn, 2012), and fail to connect virtual representations to the depicted real-life scientific phenomena (Chiu, 2010). Research that combines physical and virtual labs either sequentially or side-by-side demonstrates that careful consideration of physical and virtual affordances can support the development of scientific understanding (Blikstein, Fuhrmann, Greene, & Salehi, 2012; Olympiou & Zacharia, 2012).

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Augmented virtual technologies offer an innovative approach to science laboratories by combining virtual and physical components to provide enhanced educational experiences (Lindgren & Johnson-Glenberg, 2013). Augmented virtual technologies use virtual tools to represent scientific phenomena (e.g., simulations, visualizations) that are enhanced by using physical real-life objects as controls. This paper focuses on the pilot testing of the *Frame*, a specific augmented virtual technology that uses probeware (i.e., temperature and pressure sensors) as inputs to simulations of scientific phenomena (Xie, 2012), enabling students to use real-world objects to control the simulation. For instance, instead of students moving a gas-filled piston with a mouse in a simulated environment, students impart a force on a physical spring that inputs the information into the simulation.

The overall goal of this study is to explore if augmented virtual science laboratories such as the Frame can be used in authentic classroom settings to help students develop scientifically normative explanations of gas properties. In particular, this study seeks to answer the following questions:

1. Can augmented virtual Frame labs help middle school students develop explanations that connect molecular behaviors to macroscopic properties of gas?
2. Can augmented virtual Frame labs help middle school students refine alternative ideas about macroscopic gas phenomena?

2. Background

2.1. Supporting science learning through grounded knowledge integration

Students enter the classroom with a wide range of experiences that contribute to the framework with which they interpret the world (Bransford, Brown, & Cocking, 2000). Students' experiential understandings can serve as fruitful places to build understanding, but can also counter and even interfere with developing scientifically normative explanations of phenomena (Duschl & Gitomer, 1991). Research demonstrates that students often struggle to understand difficult science concepts because they have trouble integrating scientifically normative explanations into their existing knowledge base (Clough & Driver, 1985; Erickson & Tiberghien, 1985; Jones, Carter, & Rua, 2000), especially for topics that include unobservable levels, such as gas laws and kinetic molecular theory (e.g., Nakhleh, 1992; Novick & Nussbaum, 1981). Students often confuse molecular and macroscopic levels of a phenomenon (Ardac & Akaygun, 2004; Ben-Zvi et al., 1986) or misattribute characteristics of one level to another (e.g., Wilensky & Resnick, 1999). Students' alternative ideas about molecular behaviors can stem from everyday macroscopic experiences. For example, many students believe that when there are more particles in a fixed container, particles have less room to move and thus move slowly (Levy, Novak, & Wilensky, 2006). Conflicts between experiential and scientific understandings can be challenging to overcome but can also serve as particularly fruitful places to help students engage in conceptual change or the restructuring of ideas (Posner, Strike, Hewson, & Gertzog, 1982; Vosniadou, 1994). Providing students with opportunities to make and refine connections between everyday and normative ideas can be particularly successful for science learning (Clark, 2006; Clark & Jorde, 2004; Levy & Wilensky, 2009; Shen & Linn, 2011).

To help students make connections among molecular and macroscopic levels and help students leverage everyday ideas with the Frame, this study uses a knowledge integration (KI) learning perspective. The KI framework provides guidance for instructional strategies that encourage students to use their existing knowledge base and build understandings by making, refining and sorting connections among ideas (Clark, 2006; Linn & Eylon, 2011). Creating an environment that fosters knowledge integration elicits students' existing understandings, adds new ideas for students to consider, gives students with an opportunity to distinguish between ideas, and provides a framework for students to sort these ideas (Linn & Eylon, 2006). KI values experiences where students bring their experiential and scientific knowledge forward, so that conflicts can be identified and connections made to create more cohesive networks of understanding (Linn & Eylon, 2011). Many studies demonstrate how KI instructional strategies help students develop connected understanding of science (Chiu & Linn, 2014; Linn, Davis, & Eylon, 2004; McElhaney & Linn, 2011; Zhang & Linn, 2011).

We also leverage embodied and grounded approaches to cognition as a framework for learning from augmented virtual technologies. Embodied cognition perspectives recognize the role of bodily actions on cognition (e.g., Lakoff & Johnson, 1980; Wilson, 2002). Grounded approaches to cognition contend that the mind stores information across perceptual, motor, and affective states and uses an integrated multimodal representation to build knowledge (Barsalou, 2008). Thus, conceptual understanding involves and connects to ideas that are grounded in the experiences of the learner, which complements the importance of experiential ideas in the process of knowledge integration (e.g., Clark, 2006; Lewis & Linn, 1994). A learner's understanding of a science concept involves a network of ideas associated with what he or she sees, hears, and feels during instruction, as well as past networks of ideas associated with other, prior learning. Embodied approaches to learning — that is, having students learn material through physical interaction as well as through seeing and hearing about the material - can result in improved conceptual understanding (e.g., Abrahamson, Gutiérrez, Charoenying, Negrete, & Bumbacher, 2012; Anastopoulou, Sharples, & Baber, 2011; Tolentino et al., 2009).

2.2. Physical labs in science classrooms

Science instruction has traditionally used hands-on laboratories to help activate experiential ideas and engage with scientific phenomena. Physical laboratory experiences benefit students by incorporating concrete objects in science learning; some students can better engage with science when they are able to touch, move, and examine real objects (Feisel & Rosa, 2005). Physical laboratories also give students opportunities to interact directly with the scientific phenomena being studied (Lunetta, Hofstein, & Clough, 2007).

Despite the widespread use of physical labs in science, hands-on (not computer-based) labs typically do not provide representations for unseen levels such as atoms and molecules (e.g., Hodson, 1996; Hofstein & Lunetta, 2004; Tobin, 1990). As a result, students can have difficulty connecting physical labs with molecular-level ideas and can have difficulties integrating observable and molecular accounts of phenomena (Gabel, 1999; Johnstone, 1991). For example, students can engage in a gas laws lab that investigates the relationship between pressure and volume to help them understand the inverse relationship that as one gets bigger, the other decreases. However, after