Design Principles for Science Laboratory Instruction Using Augmented Virtuality Technologies

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Abstract: This poster highlights design principles derived from piloting augmented virtuality laboratory (AVL) activities in secondary science classrooms. Our AVL activities leverage affordances of physical and virtual manipulatives through use of connected probeware and dynamic visualizations. To help students make connections among molecular and observable levels, we developed curricular materials with a scaffolded knowledge-integration approach. Observations, students' responses, and interview data were analyzed to extract design principles to inform future implementations of AVL and other mixed-reality approaches.

Introduction

Science laboratory experiences allow students to interact directly or indirectly with the material world using scientific tools, methods, models, and theories (National Research Council [NRC], 2006). Laboratories typically incorporate physical experiences, whereby students can directly interact with scientific phenomena (i.e. using physical manipulatives; Gire et al., 2010), or virtual experiences, where dynamic visualizations are employed so that students can interact with scientific phenomena, especially phenomena that are not directly observable. Although physical laboratory experiences are widely used, physical labs do not always succeed in developing student understanding (Finklestein et al., 2005), as misunderstandings persist and are increasingly common with invisible phenomena (e.g. Eylon & Silberstein, 1987). Virtual laboratory experiences using software and simulations can benefit student learning (Honey & Hilton, 2011), yet even these types of experiences can lead students to emphasize superficial components of a phenomenon (Lowe, 2004) and fail to connect the virtual representation to scientific phenomena observed in the real-world.

Existing research indicates that sequential implementation of physical and virtual experiences is promising in terms of student learning (Gire et al., 2010, Zacharia & Olympiou, 2011). Other research demonstrates that connecting physical and virtual experiences has potential for learning (e.g. Moher, 2006). For example, Blikstein and Wilensky (2007) use connected sensors to real-time computer displays in a *bifocal modeling approach* to compare physical data to student-generated models side-by-side. Our work builds on these efforts and *simultaneously* combines probeware with dynamic molecular visualizations. Specifically, this poster presents findings from classroom tests of the Frame, an augmented virtual technology that uses physical sensors to drive a molecular simulation (Figure 1; Xie, 2012). With the Frame, students control a visualization of gas molecules in a chamber with physical manipulatives (scientific sensors). For example, students place jars filled with hot water near a temperature sensor to increase the temperature of the simulated gas. Additionally, they may physically push on the Frame that translates to the increased force on the virtual piston in the simulation. The simulation component of the frame offers a dynamic visualization through which students can also interact using a touch-screen interface. Simultaneous connection of physical and virtual manipulatives gives students the opportunity to link molecular and observable levels by manipulating physical objects and seeing resulting molecular behavior. This poster presents preliminary design principles for AVLs and aims to inform other mixed-reality approaches used in authentic classroom settings.

Conceptual Framework and Methods

To help students build upon their own prior knowledge and make connections between ideas, we combined the Frame labs with a knowledge integration (KI) approach (Linn & Eylon, 2011). Specifically, we draw from scaffolded KI metaprinciples and KI patterns of *eliciting, adding, developing criteria for and reflecting upon ideas* to maximize student learning with the Frame labs.

To understand, utilize, and refine design principles concerning the implementation of AVL activities in secondary science settings, we use a design-based research approach (The Design Based Research Collective, 2003). By conducting contextualized experiments in classrooms to test hypotheses regarding learning outcomes, we aim for the systematic design of principles geared towards the development of effective classroom interventions.

We draw our design principles from four main cycles of implementations involving over 400 students in two different middle schools and three different high schools in the U.S. mid-Atlantic region. The first cycle consisted of usability studies in a high school classroom and clinical setting. The second cycle implemented AVLs with 6 teachers and 13 classes using a pre/post design. The third cycle involved 5 teachers and 10 classes comparing AVLs to traditional labs. The fourth cycle involved 4 teachers and 13 classes comparing AVLs to virtual labs. Data gathered included pre/post/delayed conceptual assessments, classroom observations and videos, and student and teacher interviews, In each implementation, students completed the AVL following brief introductions by their physical science or chemistry teacher. Groups of 2-3 students worked together to complete the unit. Evaluation of several curricular approaches coupled with analysis of students' pre-/posttest data, curriculum responses, and interviews lead to the development of design principles for AVL.

Preliminary Findings, Conclusions, and Implications

Design principles are still being refined from analysis of classroom runs. Preliminary design principles include:

Help students distinguish ideas by problematizing content. Students made more progress in developing molecular explanations of pressure when asked to distinguish their understanding of pressure through a more advanced topic of partial pressure as compared to directly developing an explanation of pressure. For example, when directly asked for a molecular explanation of pressure, many students' explanations of pressure failed to involve collision frequency with container walls or any molecular-level description. However, in other trials where students had to distinguish their understanding of pressure by figuring out the contributions of different kinds of gases, students provided more scientifically normative molecular explanations for the phenomenon.

Explicit, intuitive correspondence between physical and virtual counterparts. Students often made flawed connections or assumptions between the physical input and the visualization. For example, in the Frame, a real-life syringe controls the number of molecules in the simulation. Pushing in the syringe adds molecules and pulling out the syringe removes molecules. However, some students assumed that the volume in the physical syringe was directly connected to the volume of the virtual container. Similarly, some students believed that the visualization literally depicted the hot and cold jars that were used to control the temperature of the simulation. Designers of mixed-reality technologies need to pay special attention to the kinds of ideas that students bring to both types of interactions.

Encourage multiple simultaneous interactions, preferably "in competition". During the first and second phases, students largely divided the work so that one person recorded observations and explanations while the other student interacted with the AVL. Little collaboration or group knowledge- building occurred. However, observations revealed that successful groups interacted with the AVL at the same time with "competing" inputs. For example, one student would control the force through the spring and another would control the number of molecules with the syringe, spurring meaningful conversations about the connections among these variables. In subsequent iterations, the curriculum was changed to encourage this kind of student interaction.

Our findings highlight the importance of iterative refinement of both technologies and supporting curricula. AVL is an emerging technological application in science classrooms, thus this work has implications regarding implementations of these types of mixed-reality experiences in authentic classroom settings.

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