WHITEPAPER

Learning in the Digital Age:
A Review of the Research on Innovative Technologies

Introduction

Current research demonstrates that through hyper-realistic visuals, interactive components and a user-friendly interface, teachers and students alike undergo learning gains when presented with complex science content. We live in an age where human knowledge is exponentially expanding and the demand on students to understand Science, Technology, Engineering and Mathematics (STEM) is greater than ever before. To live in the digital age means to learn in the digital age. Hence, instructional technologies must address the learning needs of a growing and diverse K-12 population.

Technology in the classroom must be adaptable and responsive, immersive and engaging, individualized and appropriate. It should provide to the learner a unique experience, not easily replicated or possible in the traditional classroom.

CLASSROOM TECHNOLOGY

adaptable

responsive

immersive

engaging

individualized

appropriate

This technology should allow students to:

- Explore and interact with STEM content and practices without the economical or ethical issues of costly consumable materials or preserved animal specimens
- Students need more opportunities to experience and recover from experimental (controlled) failure
- View aspects of science that, until now, resided only within the minds of expert scientists and engineers.

Research-based explorations of how emergent technologies serve students in K-12 space will better inform how to meet the needs of developing a strong pipeline of imaginative and innovative STEM professionals.

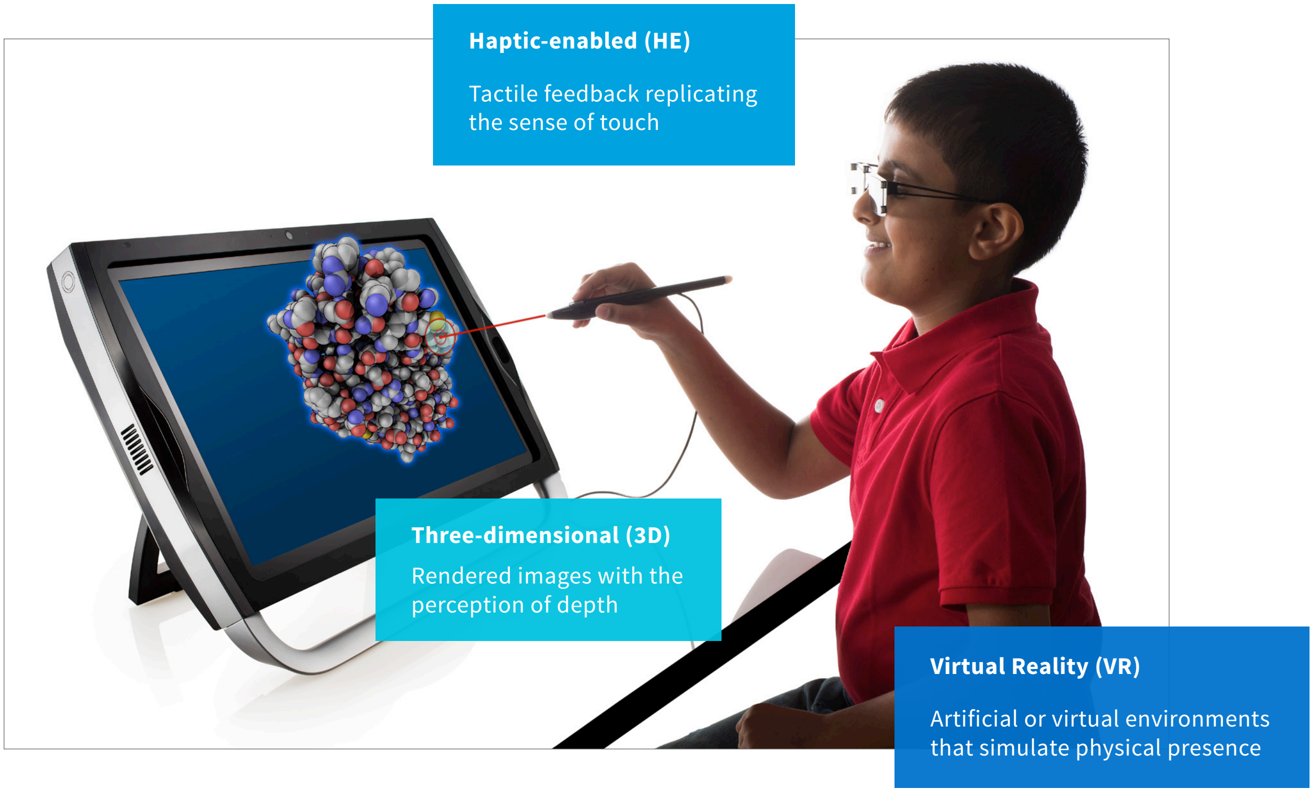
This paper explores the prospective affordances of 3D visualization and modeling; haptic and touch feedback; virtual reality and virtual environments for learning. Instructional tools that are able to incorporate these three sensory modalities have great promise for delivering STEM content in a realistic, immersive and interactive fashion to the learner. An additional benefit includes learners' preference for this technology versus more traditional modes of instruction, especially for learning complex physical and biological science concepts which present conceptual, cultural, equity, or practicability issues in the classroom

Background

A hallmark of modern K-12 education is to personalize classroom instruction with technology; providing students with unique opportunities to view and interact with authentic representations of science processes and phenomena. This initiative is a significant departure from traditional means of science instruction: Supplanting flat, two dimensional images and detached multi-media content presentations with robust three-dimensional imagery and responsive teaching.

Additionally, instructional technology that utilizes Three Dimensional, Haptic-Enabled, and Virtual Reality technologies creates a sense of realism through sight, touch and sound. Educational research has found that virtual environments convey a rich and robust experience that is both lifelike and engaging to the user.

Adapting the definition by the Organisation for Economic Co-operation and Development (OEDC) for technological innovation or innovative technologies, we can define in this paper that the combination of 3D, haptic, and virtual reality attributes within a single computer-based system are a "technological innovation."



Virtual Reality Learning Environments In Use

Because of the unique affordances of 3D, VR and HE technology, it has been leveraged in military operations preparation, medical training simulations, and teaching in university level sciences. Educational research has found that virtual environments convey a rich and robust experience that is both lifelike and engaging to the user.

Research Findings from Employing Technological Innovations in Instruction

In medicine, doctors have used virtual reality for CPR and surgical training; they reported being able to visualize the heart in real-time improved their comprehension of heart sounds and enhanced their surgical skills from the haptic or touch feedback. VR simulators have instrumental in enhancing physicians' technical skills and improving their performance in the operating room[1].

In university-level chemistry education, it has allowed students to interact with scientific phenomena at the micro-scale. Students reported when they explored and interacted with compounds and molecules in 3D, VR, they garnered a greater understanding of atomic behavior[2].

In recreation, VR simulation has evidenced its utility in the learning and transfer of complex motor skills to the real world, like learning the nuanced or subtle motions of ballet, the proper body positioning for martial arts[4], and developing the muscle memory to catch big air in snowboarding[5].

Also in current research, 3D, HE, VR technology has shown potential in increasing student engagement in learning science[6] and demonstrated benefits in developing spatial abilities in adults and children[7].

Therefore, these technologies show real promise in aiding learners that use 3D modeling in design and engineering education.

Robust Experiences for Science Learning

Technological innovations in classroom instruction use realism and interactivity to engage the student and tailor the learning environment to the individual's needs and interests. Learning through virtual reality may provide a powerful opportunity for students to engage in potentially hazardous training situations with no repercussions to live specimens, patients, or to the user.

Research using zSpace with middle and high school students[8] found that the 3D, VR, HE learning environment resulted in:

- Learning gains as demonstrated by pre- and post-test scores
- Facilitating the activation of prior knowledge
- Student progression in their questioning from asking active questions based on existing knowledge to higher-level interactive questions
- Students engaging in a pedagogically appropriate learning progession
- Students constructing higher level knowledge from their virtual experiences

Research Findings and Approach

Do learning activities with zSpace® result in student learning?

In pre- and post-tests of cardiac anatomy and physiology (e.g. complex biological systems) administered during an educational research study, both middle and high school students showed significant learning gains. [8]

Research results also indicated that zSpace® facilitated the activation of students' prior knowledge because virtual environments are active, meaning the learner must make choices or actions to advance through presented content information.

How does the virtual environment influence learning?

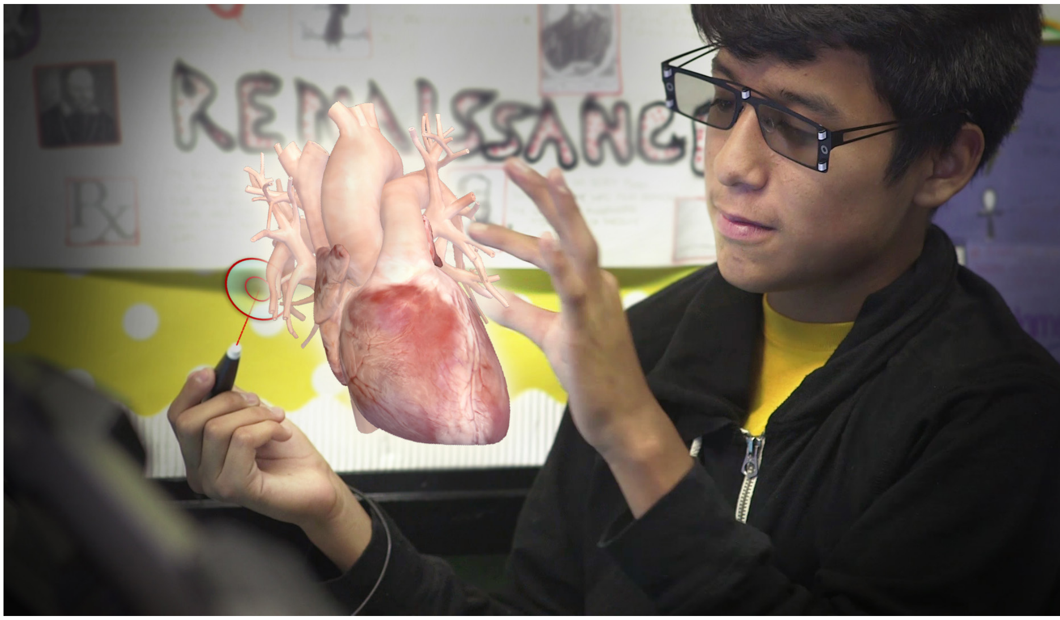
Understanding how students progress from concept to concept, through scaffolded learning experiences, towards mastery of a content domain is a learning progression (in science) or learning trajectory (in mathematics). These cognitive roadmaps are important to ensure students are learning in sequences that are developmentally appropriate to build knowledge and skills on the path towards an expert level of understanding and ability.

One method used to examine how students think about their own learning (metacognition) in active learning scenarios is through open-ended questioning. By having students record questions about what they are thinking (e.g. what do they want to learn or what is curious or interesting about the material) while they are learning, researchers are permitted a view to into how students are incorporating presented information into their thoughts or behaviors (schema).

One study with zSpace® asked students to write down open-ended questions when learning about cardiac anatomy and physiology. Results found that students transitioned from asking active questions (e.g. How does the heart use the blood?), to constructive (e.g. Why does the heart have so many chambers?), to higher-level interactive questions (e.g. How do I make sure my heart is healthy?). [8] This indicates students were engaging in a pedagogically appropriate learning progression, constructing increasingly higher level knowledge and understandings (in this case of the human heart) from their virtual experiences.

This suggests that teachers can utilize these innovative technologies to build skills and competencies through leveraging students' background knowledge, a pedagogical strategy recommended by the National Research Council, the Next Generation Science Standards and the Common Core State Standards.

Michelene Chi at Arizona State University has developed a conceptual framework for differentiating learning activities.[9] This allows for testing hypotheses of learning where active learning is more effective than passive, and learners engage in a hierarchy of activities to gain greater knowledge and understanding of a topic.



ACTIVE QUESTIONING

Students use prior knowledge to **learn** new content

Why does the heart look different than the way we draw it?

CONSTRUCTIVE QUESTIONING

Students use prior knowledge to **create meaning** from new content

How does the heart correlate with the lungs to function properly?

INTERACTIVE QUESTIONING

Students **create new meaning beyond** what was presented in the new content

What does the heart look like during a heart attack?

Students asked 36% more interactive questions after learning with zSpace.

Pre-service and in-service teachers had significant learning gains when exploring complex physical physical and biological systems on zSpace®.

Experienced teachers see value in building student interest in science and personalized learning opportunities through zSpace®.

Teachers and Virtual Learning Environments

Studies have voiced frustration from the education community that students in teacher preparation programs (pre-service) hold more progressive attitudes towards computer-based instructional technology compared to teachers currently serving in classrooms (in-service), the latter of which are reluctant to use instructional technology in their current practices. However, when presented with zSpace®, a novel instructional tool neither teacher group had prior experiences with, in-service teachers reported they preferred using zSpace® in their teaching because of its potential to increase student interest in science and the personalized learning opportunities.[10]

This suggests instructional technologies that emphasize student engagement and designed for individualized learning are perceived by expert teachers as more viable learning opportunities for science instruction than traditional (i.e. lecture, videos, textbooks, hands-on activity, etc.) methods.

Studies using zSpace® have also shown that teachers benefit from learning in virtual environments; pre-service and in-service teachers had significant learning gains when exploring complex physical (circuits) and biological (cardiac form and function) systems on zSpace[10].

Technology

There are a variety of innovative technology platforms, including desktop systems, VR headgear, and stereoscopic displays in use today. Few 3D virtual reality learning technologies are specifically designed for children and adolescent students.

Two are currently being employed K12 classroom environments: the zSpace® stereoscopic display and cell phones combined with 3D viewers.

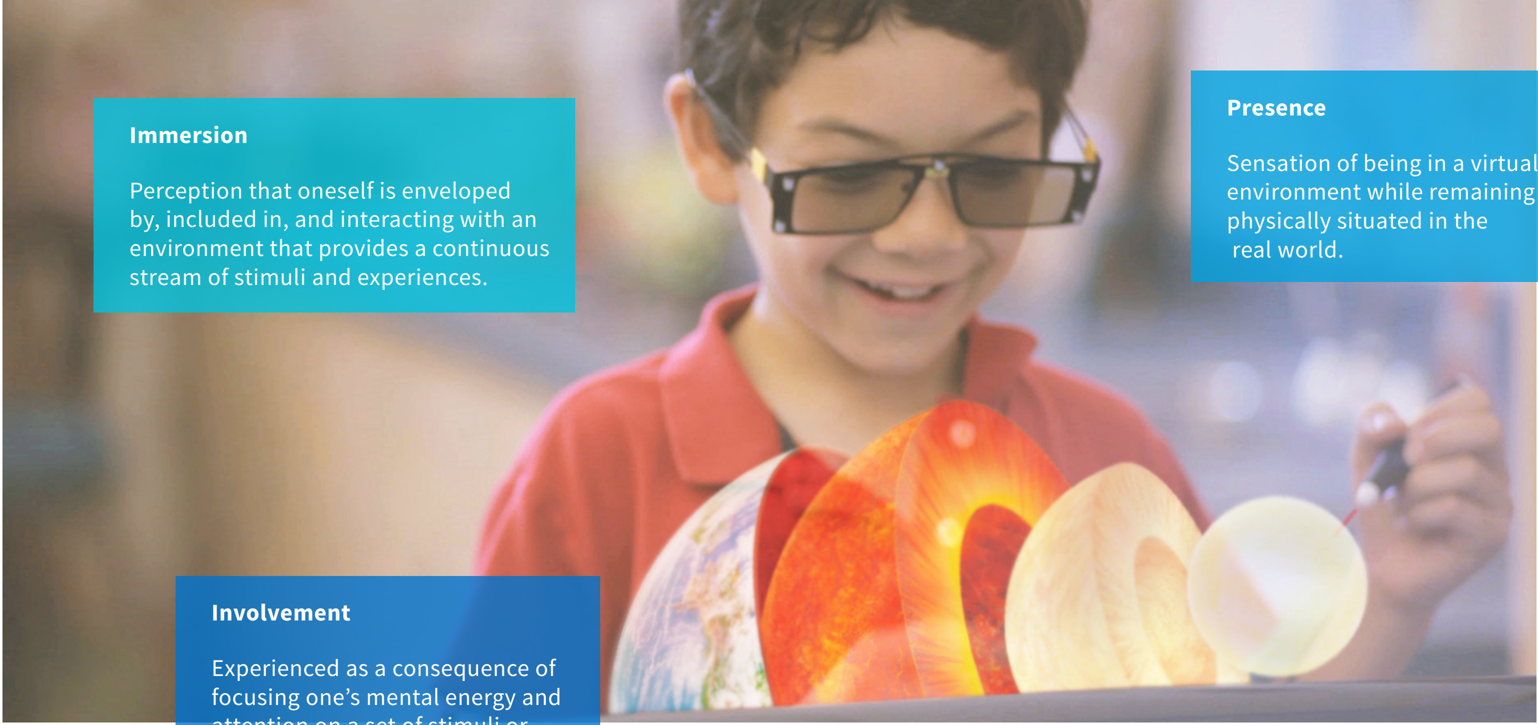
Stereoscopic Display: Innovative Technology Platform well suited to K-12

The stereoscopic display combined with the haptic enabled stylus of zSpace® is of interest since it possesses unique benefits for the user and K-12 educational settings. The display:

- Leverages multiple sensory inputs which is empirically associated with higher ratings of an immersive, realistic and engaging experience[11].
- Is intuitive and user friendly, needing only a few minutes of practice to become accustomed to the eyewear, stylus, and navigation of the virtual environment.
- Allows for dyadic interaction, where a follower can also view and discuss the VR with the primary user for peer-to-peer collaboration.
- Provides a less restrictive environment for students with disabilities or other mobility difficulties.
- Evokes minimal eye strain and VR sickness compared to other platforms[12].

Cellular Phones and Stereo Viewing Devices: Beginning to be integrated in K12

The introduction of content which creates stereoscopic images on a cell phone when viewed through a viewing device has recently been incorporated into K12 classrooms. Science curriculum companies have introduced content compatible with these devices. A pilot program is underway to understand the impacts of learning experiences with this type of platform as well as the benefits of combining stereoscopic display experiences with headmounted stereo experiences.



Immersion

Perception that oneself is enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences.

Presence

Sensation of being in a virtual environment while remaining physically situated in the real world.

Involvement

Experienced as a consequence of focusing one's mental energy and attention on a set of stimuli or related events

Exciting Opportunities in 3D, HE, VR, and zSpace®

Arguably the most important issue in developing and sustaining the American science and engineering workforce is resolving access and equity issues of under-representation (i.e. gender, racial, ethnic, and individuals with disabilities) in the STEM pipeline. Through ongoing research, zSpace® may prove vital for students from historically underserved or under-performing groups in science including:

1. English language learners who benefit from visual learning
2. Students with disabilities
3. Students with attention-based disorders who benefit from user-directed one-on-one instruction
4. Students who learn in environments with limited tools or science or safety equipment preventing their participation in hands-on activities
5. Students from diverse cultural backgrounds whose religion or values may prevent them from full participation in science experiences

The possibilities and promise of zSpace® technology continue to unfold, opening new worlds and experiences to students regardless of their previous educational opportunities, nationality, or residence.

Perceptions of virtual presence have been linked to increased student learning

Future Research in Innovative Technologies and zSpace

Presence

Research continues to formulate theories and ideas of how adults and children alike recognize, understand, and comprehend virtual spaces and virtual reality. One model of exploring how we perceive and interact in virtual environments is called virtual presence, the sensation of being in the virtual world although physically based in reality.

Virtual presence, also known as simply presence, can refine current instructional technologies to best meet the needs of younger learners. Bob G. Witmer and Michael J. Singer, army based researchers defined presence in 1998, saying presence is produced from the coupling of the user's involvement and immersion in the virtual environment[13]. Essentially, presence describes how well the user is able to control the environment, their level of sensory engagement, how well objects appear and behave as in the real world with minimal distractions.

Perceptions of virtual presence has been empirically linked to increased student engagement[14] and learning[15], therefore, maximization of both hardware and software can significantly impact learners' experiences in these virtual worlds and the instructional content presented. The educational research community agrees that K-12 and adult learners differ greatly in the abilities to self-regulate learning and participate in virtual environments. Therefore, there is a need for greater research using these technologies with younger learners in K-12 academic settings.

Knowledge Transfer

Future research will consider longitudinal impacts of zSpace® use in future science course work or science experiences. In particular, what is it that students remember about their virtual experience and the science topics presented? What types of procedural skills transferred from the virtual realm to reality?

Spatial Skills

Research has indicated that students who have more "practice" in virtual environments develop better spatial skills and reasoning[16]. Used in K-12 settings, how does zSpace® aid younger learners in this development? Reports indicate women are hesitant to enter into the engineering pipeline due their poorer self-assessed abilities in spatial thinking[17]. How may young women develop their confidence and skills in spatial acuity using zSpace®?

Conclusion

Based upon the research literature and current studies, innovative technologies like the zSpace® system have the potential to promote learning of science concepts using realistic graphics and touch technology in a user-friendly interactive and immersive interface. In a practical sense, these virtual technologies can provide to schools, teachers and students robust science experiences regardless of cost, danger, or impracticability.

Most importantly, with the use of high quality graphic images, simulated movements and auditory stimuli, innovative technologies like zSpace® enables students to fully experience science: visualize, interact with, and feel objects beyond their reach in the typical classroom. With user-directed software and teacher approved curricular activities, students can encounter gravity as it is on the Moon or Mars, dissect thousands of animals without harming a single one, build circuits without fear of failure or accidental harm, and feel the beat of the human heart in their own hand.

Special thanks to Rebecca Hite for her work in preparing the content for this document.

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