WHITEPAPER

Augmented and Virtual Reality in Education: An Examination of the Impact on Learning

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Introduction

Ongoing research has shown that emerging technologies employing augmented reality (AR) and virtual reality (VR) are revolutionizing educational experiences for K-12 learners. Coupling hardware and software, these technologies provide user-friendly controls via motion capture and styli, 3D imagery via stereoscopics, and real-time user feedback with haptic devices. The affordances of these emerging technologies are known in the research literature to enhance students' learning of content in the science, technology, engineering, and mathematics (STEM) disciplines (D'Angelo et al., 2013).

Recent research now suggests that emerging technologies can also improve learning outcomes for students historically under-represented in STEAM (including art), which include students with disabilities, English language learners, and girls. Further, these technologies have shown promise in supporting the core competence areas of social-emotional learning (SEL) and enhancing non-cognitive skills in communication and collaboration as well as providing supplemental learning experiences to enhance instruction for gifted and talented students and learners who need or want supplemental assistance.

In 2016, we reviewed research literature that suggested how emerging technologies aided users in exploring and interacting with STEM content in novel ways: reducing the need for expensive models or preserved specimens; permitting students to experience productive failure in virtual environments that allow them to change variables with ease; providing scaffolded feedback; and providing opportunities for students to try again as many times as they wish; as well as offering new ways for students to view content as if they were peering into the mind of an expert—glimpsing how scientists and engineers conceptualize abstract STEM content. We were able to conclude that these emerging technologies within an instructional context were an effective and engaging means for robust STEM learning among traditional and non-traditional K-12 students.

For 2021, this paper explores new avenues for emerging technology use in teaching STEM content for diverse learners and nurturing girls' STEM interests. We discuss how to employ emerging technologies for growing and applying students' non-cognitive skills of the 21st century to enhance their STEM learning experiences, both inside and outside of the classroom. Last, but not least, we draw conclusions about how use of emerging technologies can help to close opportunity gaps for gifted and talented as well as striving learners by providing additional occasions for rich, user-directed STEM instruction outside of the traditional classroom (e.g., before or after school, during clubs, and at home).

Emerging Technologies

Technologies whose applications are becoming more available to the public, but are understudied in regard to their potential in revolutionizing communication, business, and education (as examples)

Augmented Reality (AR)

A digital image superimposed onto the real world, providing a composite view

Virtual Reality (VR)

A computer-generated simulation of three-dimensional images within a virtual environment that can be interacted with in a seemingly real or physical way

Mixed Reality (MR)

Computer-generated environments that combine elements of the physical and virtual environments

Extended Reality (XR)

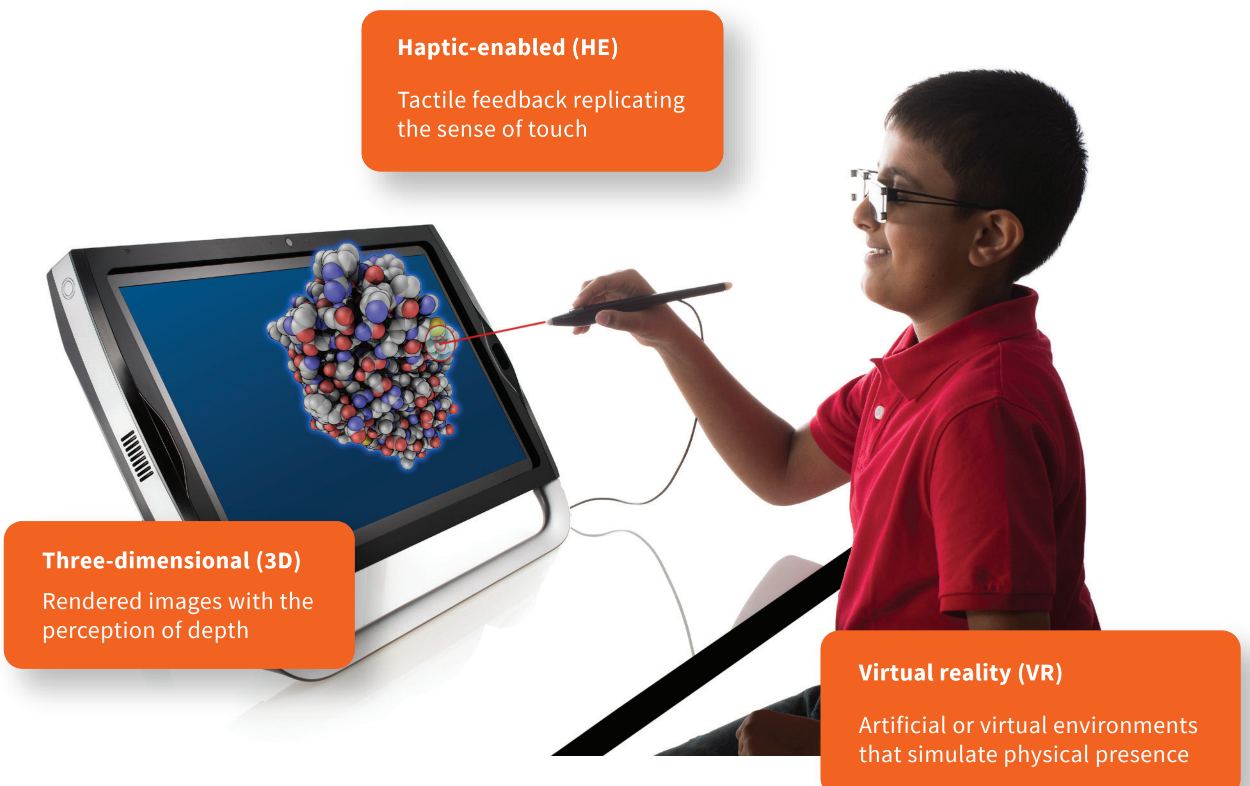
Refers to any computer-generated environment or interaction that uses AR, VR, and for MR technologies

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 multimedia 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 the combination of 3D, haptic, and virtual reality attributes within a single computer-based system as a "technological innovation."



Students with Disabilities

Students with a diagnosis of one or more of the 13 disabilities covered by the federal Individuals and Disabilities Education Act (IDEA) who qualify for special education services

Special Populations

Students who must overcome barriers to learning that require special considerations and attention for equal and/or equitable access to educational opportunities in K-12 settings

Affordances of zSpace in Learning for Special Populations

According to the National Center for Education statistics (2021), 14% of public school children in the United States, approximately 7.3 million, are eligible for special education services. The number of students identified and served has increased by one million compared to a decade ago.

The Organisation for Economic Co-operation and Development (2017) has found that the most rapidly growing subgroup of students with a disability are students with neurodevelopmental disorders (NDDs). NDDs influence how well learners are able to pay attention, regulate their emotions, and socially interact, which impedes their learning in traditional classroom spaces. Yet, students with disabilities are only a small part of the growing groups of special populations in K-12 schools. Special populations are students who experience impediments to their learning, requiring different, additional experiences to be successful in school. Not being limited to developmental concerns, special population students can experience obstacles to their learning related to garnering access to rich educational experiences.

Emerging technologies can provide additional information to special population students by creating avenues of need for STEM content and accommodating their unique needs in learning by offering control of their learning with rich sensory engagement. Research by Hite et al. (under review) sought to understand the experiences of five students with ADHD as they used zSpace for learning about the anatomy and physiology of the human heart. Students reported the system engaged their senses, was responsive to their control, and provided realistic 3D images of the human heart. In assessments of students' learning, gain scores were similar to student feedback in being able to rotate the heart (control) and view how the heart beats to circulate blood (sensory engagement and realism). This study suggests that what neurodiverse students report as affordances for learning is similar to what they experience in learning with zSpace. Given that emerging technologies are responsive to the user's inputs and interests, this suggests that other special populations can also benefit when using zSpace for STEM learning.

English Language Learners (EL)

Students who are culturally and/or linguistically diverse (CLD) who need extra suppport in classroom environments whose instruction is predominately in English

Highly Mobile Learners

Students who have intermittent or inconsistent access to learning in the classroom due to migratory status, placement/s in foster care, and/or health conditions that require frequent hospitalization

English Language Learners (EL) can benefit from directly engaging with science content with science vocabulary concurrently. Note how in this picture the student is using zSpace Studio to examine the human heart. As they grasp the fully 3D and animated model, the content-specific vocabulary is highlighted and presented to the learner together. By experiencing immersion (in the experience and terminology), the learner is better able to situate new vocabulary words to the object, which reduces anxiety, enhances comprehension, and fosters short- and long-term retention (Zou & Xie, 2019).

Highly mobile learners can benefit from scaffolded experiences with emerging technologies to enjoy high-quality instructional experiences with minimal outside assistance. Note how in this picture a student is using zSpace Franklin's Lab software to build a functioning circuit board. To guide the student in the activity, a vetted curriculum developed over the past six years with input from educational professionals facilitates student actions in the "Activity Guide."

Economically Disadvantaged Learners

Students who need financial support in, experiences with, and technical assistance to technologies due to a lack of personal (home) and/or community-based (rural, geographically isolated) access

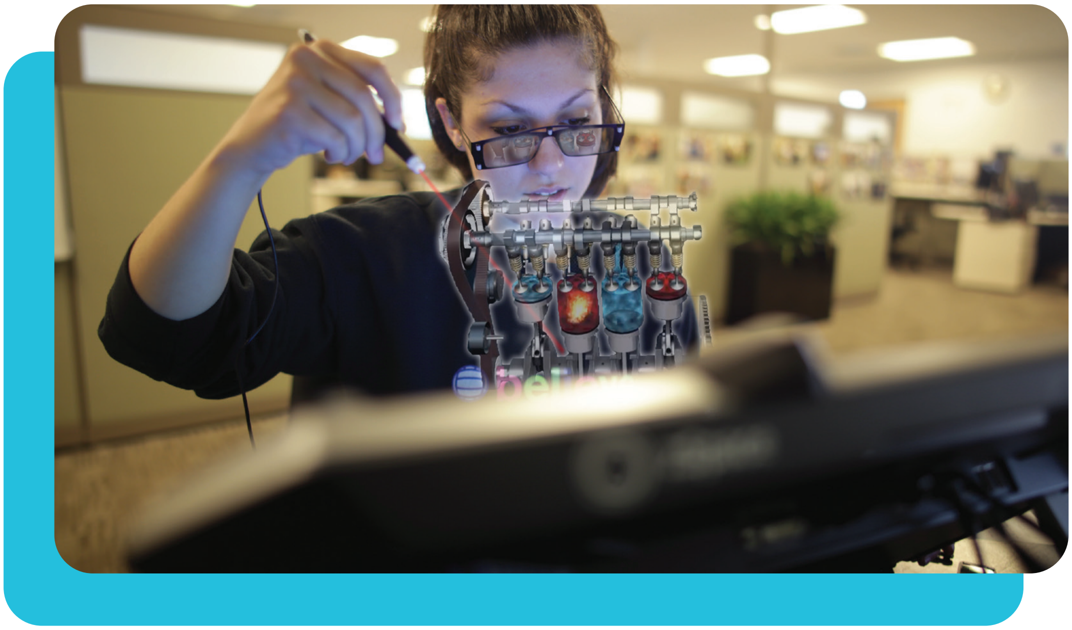
Neurodiverse Learners

A subset of students with disabilities; these learners hold a specific diagnosis of a neurodevelopmental disorder or NDD such as ADD, ADHD, and/or autism

From the guide, the learner can respond to prompts, answer selected response questions, access definitions of words, and take a photo of their work, all of which can be electronically sent to their teacher for review and scoring. With portable emerging technologies like zSpace, the classroom can come to the learner who is not in the classroom when they are ready and able to learn. During the COVID 19 pandemic, many schools realized the value of providing the immersive learning experience to students regardless of where the students were located.

In multiple districts, the portable virtual learning experience is used to deliver science lab and career and technical education (CTE) content at home. Note how in this picture, students are using innovative technology to take content (automobile engine assembly and disassembly) traditionally delivered in a lab replicating a service bay and access that content anytime and anywhere.

Affordances of zSpace in Learning for Girls: Growing Interests in STEM



According to the National Academies of Sciences, Engineering and Medicine (2020, p. 1), "careers in science, engineering, and medicine offer opportunities to advance knowledge, contribute to the well-being of communities, and support the security, prosperity, and health of the United States [yet] many women do not pursue or persist in these careers." There are a multitude of complex reasons that women are not equally represented in the U.S. STEM workforce, but a salient concern at the K-12 level is due to low or poor STEM interest (Sadler et al., 2012). Interest is defined as one's forming of relationships with an object being studied, creating the foundation from which knowledge can be built (Elster, 2007). Interest is the mixture of one's personal interest and situational interest, the latter of which is interest that is stimulated by one's environment when using new objects or engaging in novel tasks (Tobias, 1994).

Interest is vital for girls to pursue STEM. Notably, this concern does not first arise when girls are in high school as they begin to consider college and career; STEM interest must be nurtured and maintained throughout the elementary and middle grades (Wieselmann et al., 2020). Research suggests providing girls a variety of STEM learning experiences to help augment girls' interests in STEM (Bottia et al., 2015). Emerging technologies may be one strategy to provide such learning experiences and allow girls to take on the activities and persona of a STEM professional to further their interest in STEM and STEM careers (Starr et al., 2019).

Emerging technologies provide student-directed ways to engage in STEM and nurture both types of interest in STEM topics.

Personal interest can be fostered by having girls select their preferred learning activities within the virtual learning environment. Using VIVED Science and zSpace Studio software, girls may select models to view based upon their prior knowledge or interests, which makes their learning more personalized, relevant, and meaningful.

Situational interest can be generated by having girls engage in tasks that they would not normally do in the typical STEM classroom. Using Tinkercad and BlocksCAD software, girls can engage in novel tasks of computer science and math to build 3D shapes in real time to solve an engineering design challenge.

Affordances of zSpace in Motivation, Engagement, and Non-Cognitive (21st Century) Skills

Non-Cognitive Skills of the 21st Century:
The skills and abilities needed for students to be successful in a 21st century society

Communication:
To write well, listen effectively, and discuss topics intelligently

Collaboration:
To work well with others in teams, to complete tasks and co-construct new knowledge and, to apply social skills

Creativity:
To innovate by developing novel or newly adapted, valuable ideas

According to a report by the Brookings Institute (West, 2016, para. 5), “a growing body of evidence confirms that student skills not directly captured by tests of academic achievement and ability predict a broad range of academic and life outcomes, even when taking into account differences in cognitive skills.” These non-cognitive skills are categorized as intra-personal skills (such as the ability to regulate one’s behavior and persevere toward goals) and inter-personal skills (such as the ability to collaborate with others) and are key complements to academic achievement in determining students’ success. An emerging application of intra- and inter-personal skills is in Social and Emotional Learning (SEL). According to the Collaborative for Academic, Social, and Emotional Learning, “social and emotional learning (SEL) is an integral part of education and human development. SEL is the process through which all young people and adults acquire and apply the knowledge, skills and attitudes to develop healthy identities, manage emotions and achieve personal and collective goals, feel and show empathy for others, establish and maintain supportive relationships, and make responsible and caring decisions'' (CASEL, 2021). Despite how important SEL is to the development of children, many districts and schools have little time or support to embed SEL into their curricula and meaningfully into instruction (Kendziora & Yoder, 2016).

The Brookings Report, among others (Garcia, 2014), evidences a growing call in U.S. education to embed opportunities for non-cognitive skill development and application throughout the K-12 curriculum, and especially within the STEM areas.

Critical Thinking:
To think clearly and rationally such as to understand complex issues and address them effectively

Persistence:
The ability to continue in a course of action despite encountering difficulty or oopposition

Resilience:
The ability to cope mentally or emotionally with struggles in learning; and bounce back from setbacks or failures

Grit:
Combination of persistence and resilience; seeking and obtaining long-term goals, typified by a passion for completion

Emerging technologies offer virtual learning environments that encourage thoughtful decision making and avenues for productive failure. User-facilitated software can quickly assess the impact of students' choices by demonstrating the outcomes of their actions to students directly in a low-stakes context. Because these interactions are virtual, students are afforded opportunities to safely engage in novel tasks and make adjustments to their thinking without negative repercussions. In such an environment, productive failure can be viewed as a tool for learning and for building confidence in trying out ideas in the low-risk virtual space.

Emerging technologies can also provide students modalities to experience cultures and life experiences not their own, and cultures and lives throughout history (Parlier, J. (n.d.). In STEM, students can utilize virtual learning environments to relive the lives and discoveries of women in science, such as Grace Hopper, Marie Curie, and Jane Goodall. By placing themselves in the shoes of these pioneering women in science, students can begin to understand and appreciate the cultural context and historical challenges that facilitated gender-based marginalization of women scientists. Virtual experiences can foster empathy as well as the cultural awareness and competencies needed so students can garner the abilities needed to work with people from different backgrounds in an ever-growing global society (Torres, 2019).

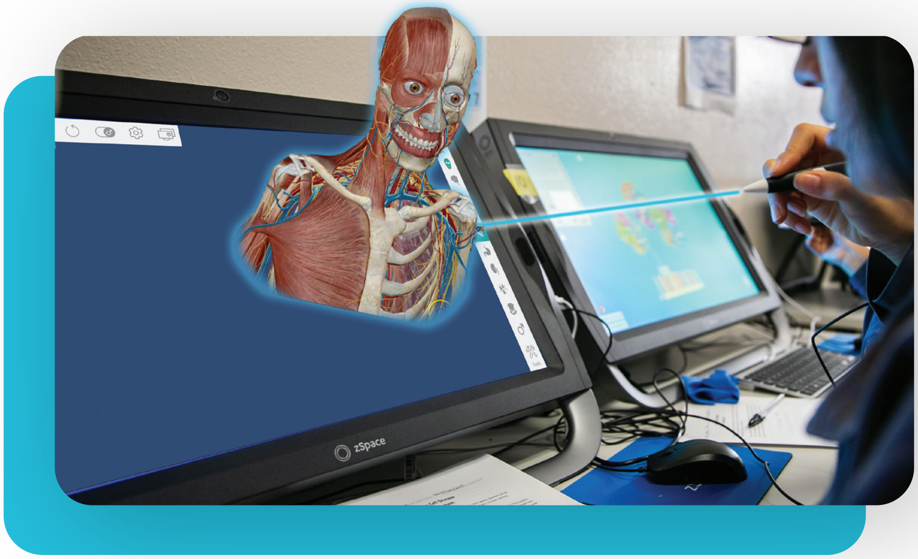
In making the case that emerging technologies are a tool to build SEL competencies, one asks the question: How do emerging technologies foster these non-cognitive skills? A study by Hite and McIntosh (2020) found that middle-grades students using Tinkercad on zSpace utilized skills in critical thinking, creativity, and grit to accomplish their engineering design task. This study suggests that students can demonstrate non-cognitive skill use when using emerging technologies for STEM learning.

Emerging technologies provide avenues for student communication and collaboration to foster non-cognitive skill development and application in STEM topics.

Intra-personal skills can be fostered by having students work through productive failure to achieve a specific STEM task. Using zSpace Newton's Park software, students can attempt to apply a certain amount of force to move an object through a hoop using various gravities, such as Earth's or the Moon's. Providing students novel learning environments allows them to try out new ideas, lending to students' growth in persistence, resilience, and grit. (zSpace, n.d.a)

Inter-Personal skills can be encouraged by having students work together in real time on tasks that encourage collaboration and communication skills. Using software like the Leopoly ShapeLab, Tinkercad, or BlocksCAD, students can co-design the construction of digital objects for 3D printing.

Affordances of zSpace in Gifted and Talented Enrichment

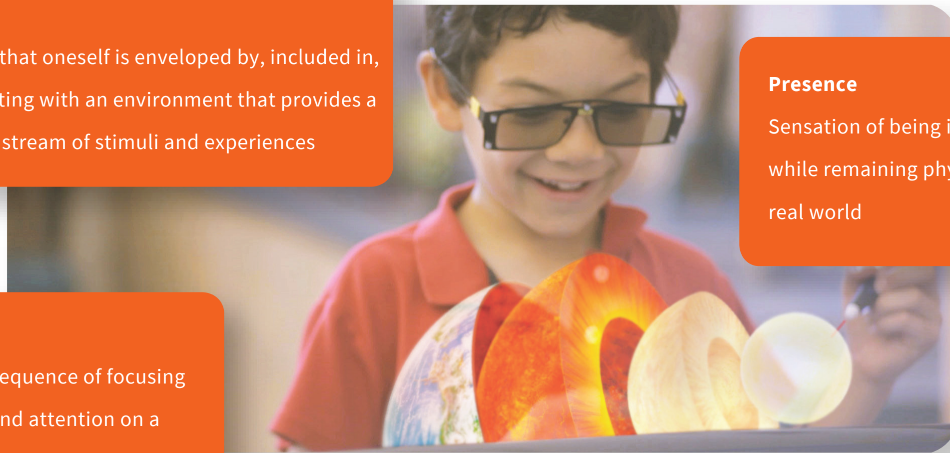


According to the National Association for Gifted Children (NAGC, n.d.a, para. 2), six percent of public school children receive gifted and talented services as defined by the Elementary and Secondary Education Act, “evidence of high achievement capability in areas such as intellectual, creative, artistic, or leadership capacity, or in specific academic fields, and who need services and activities not ordinarily provided by the school in order to fully develop those capabilities.”

Research suggests that gifted students require gifted programming and gifted experiences, which is difficult since there is a lack of training for teachers in gifted education and the pressure from federal testing causes teachers to largely focus on striving learners (Hertberg-Davis & Callahan, 2013). Gifted services are important to ensure that gifted students, including gifted and talented students from racial or ethnic minority backgrounds, receive the full benefit that gifted programs and experiences provide for college success and exemplary accomplishments in STEM (NAGC, n.d.b.; National Research Council, 2002).

Sheena Shoemaker, an anatomy and physiology instructor, shared how she used zSpace as a supplement to curriculum and instruction with her anatomy & physiology students in Maize, Kansas (zSpace, n.d.b.). Sheena described that zSpace with Human Anatomy Atlas software provided her AP students with another means to access anatomical information alongside plastic models and dissection specimens. Further, these emerging technologies made serving a large class size of gifted students much easier as students were utilizing their time wisely while independently exploring science phenomena in an information-rich virtual learning environment.

Emerging technologies can provide self-guided and additional opportunities to enrich learning, such as addressing the need for specific and robust learning experiences for gifted and talented students. Per Sheena, “I can definitely vouch for the fact that Human Anatomy Atlas and zSpace really allowed my students to study in less time and more accurately because of how good the visuals are. I didn’t have to reinvent the wheel. I didn’t have to make new lesson plans or change how I taught. I just simply taught the students how to use the zSpace, how to use the app, and they were able to then use that in their study time to make things more accurate and quicker for them” (zSpace, n.d.b, p. 4).



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

Understanding of the different types of gaps:

Ways in which social, economic, and demographic factors contribute to students (groups) having lowered aspirations, achievement, and attainment in education

Opportunity Gap

Different inputs to education; the unequal or inequitable distribution of resources and opportunities (variance of resources among different groups)

Achievement Gap

Different outputs to education; unequal or inequitable distribution of resources and opportunities (variance of resources among different groups)

Learning Gap

Performance of individual students relative to expectations set at their age or grade level

Closing the Opportunity Gaps

In the landmark legislation that established the Elementary and Secondary Education Act of 1965 and the most recent reauthorization of Every Student Succeeds Act (ESSA), there has been a strong impetus to close achievement gaps that were the outcomes of unequal and inequitable access (known as opportunity gaps) to a quality education. To ensure a quality education, many school districts and localities are expanding the learning outside the school day and/or extending the learning at home to close opportunity gaps and equilibrate achievement across student groups, regardless of their socio-demographic backgrounds or geographic contexts.

Policy research suggests an increase in the availability of more STEM-related activities to youth through extracurricular experiences (Bottia et al., 2015) and at home (Galindo & Sonnenschein, 2015).

Emerging technologies provide new avenues for access to STEM content and learning to close opportunity gaps in schools and communities.

Afterschool programs, clubs, and STEM enrichment classes may utilize zSpace to extend STEM learning outside of the school day. Using Tinkercad software, students with the Atlanta Public Schools are designing bat boxes to help with the sustainability of a community garden. Through zSpace-assisted opportunities in informal learning spaces, students are expanding their STEM knowledge and addressing needs within their communities (zSpace, n.d.c).

Remote and home learning provides additional opportunities for students to engage in STEM learning while not at school. Using Curie's Elements software, students can individually explore the periodic table of elements to visualize trends in columns and rows, build and combine atoms, and more using the activity guides built into the application—all from their own homes using the zSpace Laptop.

Conclusion

Based upon the research literature and current studies, innovative technologies like the zSpace® system have the potential to promote learning of science, math, and career and technical education (CTE) concepts using realistic graphics and experiences in a user-friendly interactive and immersive interface. In a practical sense, these virtual technologies can provide to schools, teachers, and students robust learning experiences that might otherwise be too dangerous, impossible, counterproductive, or expensive.

Most importantly, with the use of high quality graphic images, simulated movements and auditory stimuli, innovative technologies like zSpace® enable students to fully experience content: 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.

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