

Leveraging Digital Depth for Responsive Learning Environments

Future Prospects for Wearables, Augmented Reality, and Virtual Reality



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Executive Summary

For decades, new technologies have promised to transform education. Such claims are typically fueled by marketing campaigns, the potential for expansion into new markets, and education technologists' enthusiastic visions. Every year, educators are bombarded with top-ten technology lists that promise to transform their practice, their classrooms, and even school as we know it. Often, these market-driven approaches represent attempts by technologists to solve what they view as problems in education. While many such technological solutions are indeed effective in solving specific problems or in meeting certain needs, they typically work within the current realities of the present-day education system. Rarely do they come anywhere close to supporting transformational change.

With the spread of wearables, augmented reality, and virtual reality, education stakeholders again face the question of how developing technologies may support learning. These technologies have the potential to impact learning in significant ways. However, evaluating their best and most human-centered uses requires sifting through the hype and developing a critical filter for assessing their potential value.

This paper explores the potential for wearables, augmented reality, and virtual reality to help create more responsive learning environments that: increase student engagement, enhance the personalization of learning, increase understanding of others' experiences and perspectives, help develop greater levels of self-awareness, foster critical thinking, and increase student agency.

In exploring these technologies' future potential for education, the paper presents a frame for understanding how such technologies add a layer of "digital depth" atop physical reality. It also takes a closer look at each technology, with emphasis on its relevance to education. Building upon this analysis of the technologies' potential relevance to education, five future vignettes illustrate some ways in which wearables, augmented reality, and virtual reality could support the creation of responsive learning environments. The future vignettes are followed by insights and implications for education stakeholders to consider in evaluating potential uses of these and other emerging technologies in education and an action guide for exploring these technologies' potential in specific settings.

Moving from Hype to Impact

“Revolution doesn’t happen when society adopts new technologies; it happens when society adopts new behaviors.”¹ – Clay Shirky

For decades, new technologies have promised to transform education. Every year, educators are bombarded with top-ten technology lists that promise to transform their practice, their classrooms, and even school as we know it. Often, these market-driven approaches represent attempts by technologists to solve what they view as problems in education. While many such solutions are effective in solving specific problems or in meeting certain needs, they typically work within the current realities of the present-day education system. Rarely do they support transformational change.

With the spread of wearables, augmented reality, and virtual reality, education stakeholders again face the question of how developing technologies may support learning. These technologies have the potential to impact learning in significant ways. However, evaluating their uses requires sifting through the hype and developing a critical filter for assessing their potential value.

As highlighted in KnowledgeWorks’ 2015 forecast, [*The Future of Learning: Education in the Era of Partners in Code*](#), wearables, augmented reality, and virtual reality could be used to support the creation of responsive learning environments, or learning biomes. This provocation raised the possibility that these developing technologies might facilitate the creation of more inclusive, positive group learning environments that would support students in cultivating the knowledge, skills, and dispositions that they will need to succeed in the future:

Education innovation will focus on fostering responsive learning climates through the cultivation of effective group learning cultures and the customization of learning environments for individuals.

Attention to factors such as emotional intelligence, social awareness, and the gender spectrum will contribute even as ubiquitous sensors and sophisticated feedback loops make it possible to optimize physical and digital environments for learning. By creating tailored personal and shared learning overlays, augmented and virtual reality tools will increasingly meld those environments and enable learners to make use of new forms of immersive experience.

This paper looks into this provocation, exploring the potential for wearables, augmented reality, and virtual reality to help create more responsive learning environments that increase student engagement, personalization, understanding of others’ experiences and perspectives, self-awareness, critical thinking, and student agency. Despite potential benefits, we know from previous technology cycles that adopting these technologies in education without a human-centered frame is unlikely to create significant benefit for education systems or for individual learner development.

Given that tension, education stakeholders need to think critically about how these technologies might support learning today, while also bearing in mind future possibilities. In looking ahead ten years to explore potential uses of wearables, augmented reality, and virtual reality in learning, this paper aims to provide educators, administrators, and other education decision makers and influencers a framework for evaluating potential applications of these technologies from a human-centered point of view. The paper considers how these technologies might be used to support the creation of new kinds of learning experiences and to enhance existing learning experiences.

Supporting Responsive Learning Environments

Wearables, augmented reality, and virtual reality have the potential to support the creation of responsive learning environments because they can assist educators and other education stakeholders in creating experiences characterized by immersion, embodiment, contextualization, and self-awareness. The table below defines these experience factors.

Experience Factor	Definition	Potential Learning Benefits
Immersion	Intense involvement and engrossment in an action, setting, experience, or environment.	<ul style="list-style-type: none">• Can enable deeper understanding and connections to material and concepts.• Can support simulation of real-world contexts or actions.
Embodiment	The representation of ideas, identities, experiences, and/or concepts in tangible forms.	<ul style="list-style-type: none">• Can aid in understanding different perspectives and points of view, supporting development of critical thinking and social-emotional skills.• Can help make concepts more vivid.
Contextualization	The placement of something, such as a word, action, place, or event, into a larger frame that provides more information.	<ul style="list-style-type: none">• Can enable development of deeper understanding or comprehension of a concept or subject.• Can enable students to share their perspectives in relation to the object or place of interest.
Self-Awareness	Clear perception of one's strengths, weaknesses, emotions, and motivations.	<ul style="list-style-type: none">• Can lead to increased levels of self-knowledge, supporting greater degrees of purpose and student agency.• Can support reflection on learning, including the creation of personal learning profiles.• Can support learners in setting and pursuing goals.

These experience factors could be used by educators and students to create responsive learning environments that enable healthy relationship building, self-awareness, and social understanding in support of individual and group learning needs. For example, looking ahead ten years:

- New streams of data, enhanced connectivity, and new platforms for collaboration could provide learners with personal, just-in-time learning supports.
- Classmates could collaborate on challenges in simulated environments, discovering which kinds of responses and behavior yield the best outcomes.
- Individual and group project work sessions could be documented in ways that enable students to monitor their own performance data so as to cultivate self-knowledge and awareness.
- Educators and policy makers could engage in virtual experiences that allow them to assume the identity of a student or parent in need, developing greater insight into the behaviors, rationales, and responses that ought to be addressed in policies and the empathy required to act on this insight.
- Learners and educators could layer digital information over the physical world in order to build context around important issues.

Such future possibilities highlight some ways in which wearables, augmented reality, and virtual reality could support the creation of responsive learning environments. Looking across these possibilities, these technologies may also help to make learning more relevant and interest based, contribute to social-emotional learning and skill development, and extend and enhance learning experiences that may not be offered locally.

Before exploring future vignettes illustrating these possibilities, the paper presents a frame for understanding how wearables, augmented reality, and digital reality add a layer of “digital depth” atop physical reality. It also takes a closer look at each technology, with emphasis on its relevance to education.

Creating Digital Depth

Wearables, augmented reality, and virtual reality alter the physical world by layering data, computing, and connectivity onto our physical environments and adding “digital depth” to our physical experiences. Digital depth offers new kinds of spaces in which immersion, embodiment, contextualization, and self-awareness can be used to create novel or enhanced learning environments. Over time, as wearables, augmented reality, and virtual reality continue to mature, they will become increasingly powerful. They will also merge with each other and with other technologies, expanding and deepening the layers of digital depth around us and potentially contributing to the creation of responsive learning environments that support students and educators in achieving desired learning outcomes.

Digital depth is the layering and integration of data, computing, and connectivity onto physical environments.

Three kinds of spaces are emerging from the growth of digital depth:



Enhanced physical spaces are grounded in physical reality but have a thin layer of digital information capture, sharing, and feedback. They have relatively low digital depth. Wearables are effective in creating enhanced physical space.

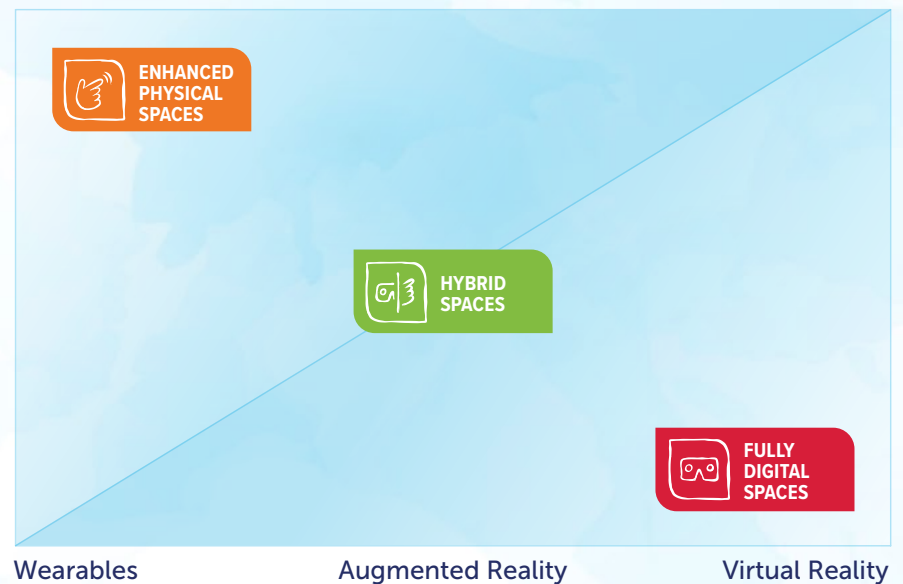


Hybrid spaces use multiple digital layers and more extensive computer-generated content, connectivity, and experiences to enable experiences that have a higher degree of digital immersion but which are still anchored in physical space. Hybrid spaces have moderate digital depth. Augmented reality creates hybrid spaces with new capabilities for collaboration, visualization, and creation.



Fully digital spaces provide full immersion in digitally created environments with little reference to physical space. Because of their high levels of digital depth, they can allow for novel world building and for shifts in identity and perspective through embodiment, or taking on the identity and context of another person or character. Virtual reality supports the creation of fully digital spaces.

Digital Depth Spectrum



Together, these spaces form a digital depth spectrum as illustrated above. Each type of space supports a different degree of immersion, embodiment, contextualization, and self-awareness.

Technology Digest

To aid understanding of how wearables, augmented reality, and virtual reality contribute to digital depth and can support the creation of responsive learning environments, this section takes a closer look at each of these technologies. Moving from less to more digital depth, each technology digest includes a description of the technology and its key benefits along with examples of its current uses, future directions, and significance in education.

Wearables

Dynamic Feedback Enhances Personal Awareness and Performance

Wearables are devices that can be worn by the user to collect data through sensors and transmit it wirelessly, allowing for the seamless tracking of personal data such as fitness, health, location, sleep, and other biometric data (for example, respiration and heart rate). Wearables include personal devices such as smart watches, fitness monitors (for example, the Fitbit), smart jewelry, and clothing. With their focus on collecting user-generated data and their grounding in physical reality, wearables typically enable the creation of **enhanced physical space**.

Key Benefits

As a form of personal digital accessory, wearables can provide individuals with deeper levels of self-knowledge, enabling greater agency and self-improvement. The quantified-self movement builds on this opportunity, with members of the movement collecting data of all kinds on themselves, including categories such as health, social, environmental, and emotional. The data is used to gain a better understanding of oneself, an effort best described as better living through data. Wearables can help individuals track their performance against personal goals and attain desired outcomes.

Current Uses

This sub-section presents current uses of wearables that could be relevant to education, along with examples demonstrating specific applications for each use.



Personal Feedback Ecosystems

Wearables provide individuals with opportunities to configure personal feedback ecosystems to help improve health, wellness, and performance.

- **AIO Smart Sleeve:** A smart sleeve that measures heart rate, sleep, body temperature, air temperature, UV rays, and stress.
- **Apple Watch:** A watch that combines calendaring, messaging, biometric tracking, GPS, and other functions to provide personal coordination and health management.
- **Lechal's Smart Insoles:** Smart footwear with haptic feedback that uses simple vibrations to provide detailed route guidance; fitness stats such as steps, miles, and calories burned; and downloadable maps.

Personalized Expression

Digital accessories and clothing allow individuals to express their moods and identity through enhanced connectivity, LED lights, and emotion. Other devices enable users to personalize environments through digital enhancements such as audio.

- **Neurowear:** An animatronic tail that wags to express the user's emotion.
- **VFiles x XO:** Fiber-optic-embedded caps and rucksacks that enable the wearer to change the surface patterns and colors based on their responses to music.

Emotion Management

Emotion-based wearables use electroencephalography (EEG), galvanic skin feedback, and other metrics as an interface to help individuals develop greater awareness of their emotions for the purpose of self-regulating to a desired emotional state. Some EEG-based devices stimulate particular emotional states such as feelings of calm or energy.

- **Emotiv:** An EEG-based headband that monitors brain activity to detect patterns of distraction, engagement, stress, focus, relaxation, interest, and excitement.
- **Spire:** A device worn on the waistband or bra strap that analyzes breath rates to determine levels of tension, calm, or focus.
- **Touchpoints:** A device that measures a user's stress level and uses vibrations to soothe the person. The device can be worn on a user's wrist, held, or clipped to clothing.

Future Directions

In the future, wearable devices will connect more seamlessly with other networks, providing even more information to aid in understanding personal performance patterns and opportunities for intervention in specific contexts. Such networks will include transaction networks for transferring funds and purchasing products and services; social networks that alert members of social groups

and share information; and the Internet of Things, which can connect smart objects and provide automated services. Additionally, machine intelligence and algorithms will analyze personal data from wearables and make suggestions to nudge individuals toward desired behaviors. Expect to see wearables become more integrated with augmented reality and virtual reality experiences as interfaces that collect a wide variety of performance and user data continue to advance.

Significance for Education

Wearables could provide learners, educators, and other stakeholders with an expanded range of data capture and feedback. Such feedback has the potential to provide the benefits for learning listed below:

- Support increased awareness of learners' emotional selves; physical wellbeing; patterns of behavior; and opportunities for self-improvement, support, and interventions.
- Enable more accurate goal setting in support of positive behavior and social-emotional learning.
- Support deeper personalization by linking real-time personal data to time and place, illuminating what physical places, times of day, diet, social groups, types and amounts of physical activity, and cognitive and social activities best facilitate learning for individual students.
- Support the creation of more responsive feedback ecosystems that provide quick-cycle information for use in learning.
- Provide data for measuring social-emotional learning.
- Increase student agency by offering learners the opportunity to self-manage and regulate their performance, and to become more active in seeking out optimal learning environments based on expanded self-knowledge.
- Collect expanded data about barriers to learning.

Augmented Reality

Rich Visualization Deepens Understanding and Experience

Augmented reality overlays digitally generated content onto a user's view of the real physical world. Augmented reality can be accessed with simple devices such as smart phones or tablets, as well as with pricier headsets and hardware.

In relatively simple augmented reality applications, aiming a smart-phone or tablet at a designated point in the physical world reveals a layer of digital text, graphics, animations, and/or videos that can make still objects come to life and provide contextual information. For example, the Google Translate app automatically translates unfamiliar text when users point a smart phone's or tablet's camera at it. In another example, the messaging app SnapChat provides users with filters that allow them to overlay animated graphic enhancements, such as funny hats, mustaches, and dog ears on their subjects, augmenting the reality of the subject and setting.

More data- and computing-intensive augmented reality can overlay three-dimensional virtual objects, or "holograms" (for example, a three-dimensional human brain), onto physical places. As such overlays become more sophisticated and larger, the virtual objects play a more prominent role, and the physical and virtual realms are integrated in ways that create a richer, more interactive experience.

Whether relatively simple or more complex, augmented reality overlays digital images on top of the physical world, creating **hybrid spaces** with varying degrees of digital immersion and enabling greater contextualization than is possible in just the physical world.

Key Benefits

Augmented reality enhances the physical world through its capacity to create dynamic visualizations of concepts, data, and artifacts. In so doing, it infuses physical settings with images that can inspire wonder, awe, curiosity, and imagination. By integrating the digital and physical worlds, augmented reality produces novel environments that allow individuals to interact with objects and



artifacts, such as parts of the human body or universe, mythical characters, or fictional worlds, to which they would not otherwise have access. The result is an enriched collaborative environment for exploration, inquiry, and performance.

Current Uses

This sub-section presents current uses of augmented reality that could be relevant to education, along with examples demonstrating specific applications for each use.

Information-Rich Spaces and Deep Contextualization

Digital text, graphics, and animations overlay physical settings such as a museum, classroom, or zoo to create media-rich contexts and personalized engagement with the physical environment.

- **The Cleveland Museum of Art's ArtLens App:** An app that, when used by pointing an iPhone, iPad, or Android device at a piece of artwork, reveals a high-definition image of the object along with additional multimedia information, captures the digital image for saving, and suggests navigation to related objects in the museum, creating a personalized museum experience.

- **Star Walk:** An app whereby pointing a mobile device at the night sky will reveal stars, planets, satellites, and constellations in their proper place from the user's location. Clicking the augmented reality icon will overlay the image onto the user's view of the night sky, and pointing the mobile device at the ground will cause the stars from the other hemisphere to appear.
- **Yelp Monocle:** An app that uses a smartphone's camera, GPS, and compass to display augmented reality markers containing user-generated reviews atop restaurants, stores, and other physical locations.

Interactive Geographies

Live action, role playing, and location-based games and augmented reality authoring tools can turn any physical geography into an interactive learning and gaming environment.

- **Aurasma:** An app that allows teachers and students to author their own augmented realities by uploading a "trigger" image or icon from the physical world and overlaying content atop it to create digital clues for treasure hunts, augment textbooks, or add narratives to objects.
- **Zoo-AR:** A program that enables students to download and print a selection of animal and insect "markers" that become 3D models of the animals and insects when a mobile device camera is pointed at them, creating a zoo anywhere.
- **Pokémon Go:** An augmented-reality-based videogame where players use their mobile phone cameras to spot and capture digitally rendered Pokémon that are overlaid onto physical surroundings. Players fight battles, problem solve, and explore their natural world as they play Pokémon, which has become a template for education-related, place-based games.

Interactive 3D Simulations

3D digital holographs augment physical settings to create new resource environments, performance spaces, and interactive experiences for learners. Students use goggles, lightweight glasses, or large-scale screens with gesture-based controls to access rich visualizations that support them in learning complex concepts and systems.

- **zSpace:** A 3D holographic learning platform that allows students to interact with simulated objects in virtual environments as if they are real. Students use a stylus, lightweight glasses, and a laptop to grab, manipulate, and experiment with a range of learning resources from all disciplines, such as a human heart or the Taj Mahal. The zSpace studio allows teachers to develop models and lessons tailored to specific learning objectives.
- **BroadcastAR:** An augmented-reality-based system that uses a mixture of the real world and digital content to create large-screen, interactive 3D holographic experiences, engaging groups with explorations of places and times such as space, the oceans, the arctic, and the Jurassic era.

Future Directions

Augmented reality is evolving quickly, with experiences becoming increasingly social and more seamlessly integrated between physical and digital spaces. As augmented reality gear such as goggles and headsets continues to develop, it will become more comfortable. Augmented reality-capable technologies will also become smaller and will be embedded into glasses and eventually also into contact lenses. Graphics and image anchoring will improve, allowing for more detailed holograms that interact more accurately and in more ways with the physical world.

In addition, augmented reality interfaces will become more organic and natural as the technology combines with gesture-based controls, which will allow the programs to respond to users' natural movement and gestures rather than relying on a controller or touch screen. It will also increasingly utilize haptic technology, a type of human-computer interaction that allows for tactile feedback and other forms of bodily sensation, giving the holograms a sense of touch and allowing for manipulation.

We can also expect to see shifts in its applications: augmented reality will be used to create shared virtual workstations where distributed teams can work on holographic objects simultaneously and collaboratively; and, as more sophisticated authoring and design tools enable users to generate more experiences, augmented reality will shift from being primarily a content-consumption tool to being a creative production tool. Lastly, augmented reality will shift from being a standalone application or program that serves discrete functions to being a more fully integrated computing system, as exemplified by the current direction of HoloLens and Magic Leap.

Significance for Education

Augmented reality's strength lies in its ability to create dynamic visualizations that enhance learning environments, including classrooms and other place-based learning settings such as museums, parks, and neighborhoods, with deep contextual information. These visualizations can also aid understanding of complex concepts, systems, and ideas such as the human brain, the universe, or a chemical reaction. Such visualizations have the potential to provide the benefits for learning listed below:

- Create deep information in place, providing enhanced context and background along with the ability to access various perspectives such as competing views on a historical event or monument.
- Enable the addition of interactive components such as quizzes, inquiry prompts, and games to artifacts, places, and physical settings, helping educators and students take action-oriented learning beyond the walls of school.
- Enable students to engage with ideas and with each other in hybrid spaces so as to develop the practices and behaviors of scientists, historians, nurses, and artists.
- Support students in experimenting and exploring possibilities in low-risk conditions, a process that is critical for developing both a systemic view of knowledge and lateral and associative critical thinking.

Virtual Reality

Immersive Embodiment Shifts Perspective and Identity

Virtual reality is a computer-simulated, immersive digital environment. While it is typically experienced through a head-mounted display such as the Oculus Rift or HTC Vive, platforms such as Google Cardboard and Samsung Gear VR allow users to experience virtual reality with only their smartphones. The more senses that are simulated – vision, hearing, touch, and even smell – the more realistic the virtual reality experience.

Some virtual reality experiences are purely spectated, meaning that they invite no interaction and that the user simply views 360-degree, three-dimensional tours or exhibits. For example, with Google Expeditions, students can take virtual field trips and feel as if they are walking on Mars or swimming in a coral reef. More intensive forms of virtual reality are more interactive and generative, with users creating virtual artwork or building three-dimensional worlds. In one such application, the Washington Leadership Academy in Washington, D.C., is building its own fully immersive and scientifically accurate virtual reality chemistry lab.

With its ability to engage users in digitally created environments that have little reference to or grounding in physical space, virtual reality is most often associated with the creation of **fully digital spaces** that can support high degrees of immersion and embodiment.

Key Benefits

Users are surrounded by digitally created objects, artifacts, scenes, and characters, creating a narrative environment that the user experiences rather than watches. In richly developed virtual reality narratives, users can embody a character, taking on its identity and experiencing the world through its social, economic, political, and cultural reality. Full immersion and embodiment allow virtual reality creators to tell stories with rich points of view, creating profound experiences that support empathy and perspective taking.



Current Uses

This sub-section presents current uses of virtual reality that could be relevant to education, along with examples demonstrating specific applications for each use.

Immersive 360-Degree/3D Exhibits and Tours

Tours enabled by virtual reality allow students to travel to places, real and imaginary, that would otherwise be inaccessible, broadening exposure to the world and sparking curiosity.

- **Discovery VR:** An immersive tour series produced by The Discovery Channel that allows students to experience nature, countries, cultures, art, and a host of topics in three dimensions.
- **Mars Experience Bus:** A repurposed school bus decked out with virtual reality technology that takes students on a bus tour of Mars. The tour is tagged to the streets of Washington, D.C. As the bus turns, slows down and speeds up, and rolls over bumps, it passes through different kinds of Martian terrain, giving students a visceral experience of the red planet.

- **Panoform:** A low-tech virtual reality application that uses a special grid and software for turning user images and drawings into virtual reality experiences. Teachers can print grids for students to color or can upload digital images into a grid and then view them using Google Cardboard.
- **SocialVR:** A browser-based authoring tool that allows users aged eight and older to create personalized virtual reality experiences. Using a simple browser, a phone, and a low-cost camera, it equips individuals who otherwise would not have access to virtual reality technology to build personalized immersive experiences using 360-degree photos and videos, along with text and audio.

Embodied Narratives and Identities

Deep immersion into context, action, and identity can create embodied experiences that can help individuals cultivate empathy and perspective-taking through engagement in seemingly lived experiences.

- **Emblematic:** An organization that produces room-scale virtual reality environments that allow individuals to step into the scene of a story and experience the action first-hand. These immersive, journalistic narratives have been used to elevate the experiences of undocumented immigrants, to explore prisoners' experiences after solitary confinement, to highlight hunger in Los Angeles, and to depict the experiences of Syrian refugees.
- **The Machine to Be Another:** An embodied virtual reality system that allows anyone to experience the world from the perspective of another.

Free-Roaming, Immersive Multiplayer Arenas and Installations

Large-scale virtual reality gaming delivers a fully immersive experience for users to explore environments, role play, and develop practitioner behaviors.

- **MindTrek VR:** A free-roaming, warehouse-scale virtual reality game arena in which players use virtual reality headsets hooked to

portable computers worn on backpacks. Playing in groups of six to eight people, they walk, explore, and fight their way through wildly different virtual terrains that are littered with virtual obstacles.

Immersive 3D Creation and Collaboration Spaces

Virtual reality can extend school facilities and educational resources by simulating science labs, art studios, and other creative spaces.

- **Tilt Brush:** A painting program where users create art on a three-dimensional canvas in virtual space using painting tools and colors.
- **Alice:** A block-based programming environment that lets teachers and students easily create 3D environments, animations, interactive narratives, or program simple games.
- **Labster:** A virtual chemistry lab that provides simulations for experiments and projects in STEM curriculum using a mobile phone and headset. Evaluations have shown that Labster doubled science teachers' impact on student learning compared to traditional teaching.

Future Directions

After decades of speculation and waiting, virtual reality finally arrived into mass markets in 2016 and is advancing at a rapid rate. We can expect virtual reality headsets to shrink and to become untethered, no longer having to be wired to a computer. In addition, haptic interfaces will bring more sensory experiences to virtual reality; in one example, Disney Research's immersive haptic chair gives users body sensations triggered by user movement, biofeedback, or story timelines. Lastly, as artificial intelligence becomes more integrated into virtual reality software and automates the procedures generating virtual reality worlds, users' movements through these worlds will trigger the creation of continuous, dynamically generated virtual realities.

Significance for Education

Virtual reality can provide immersive narrative experiences and high degrees of embodiment. Such immersive and embodied experiences have the potential to provide the benefits for learning listed below.

- Provide a platform for students to interact with others regardless of geography, allowing them to collaborate in the same virtual environment no matter where they live. Support individuals in exploring other identities and expanding empathy, compassion, and perspective-taking.
- Practice and develop metacognitive skills that expand people's understanding of diverse socio-economic realities, sensitive issues, and challenges.
- Through the creation of simulated worlds and situations, allow students to try a wide variety of experiences regardless of where they live or their socioeconomic status.
- Provide a digital setting for assets such as science labs that might otherwise be out of reach for schools dealing with limited resources or space.
- Enable teachers and curriculum developers to devise novel ways of addressing pressing challenges such as racial bias in curriculum, as well as post-traumatic stress disorder and other forms of trauma.
- Create conditions for experiencing emotions such as awe, wonder, joy, and bliss.
- Support learners and educators in practicing and developing effective emotion regulation strategies and other social-emotional skills.
- Enable students to display mastery of competencies, concepts, and content and to engage in problem solving in new and unique ways through simulations and world building.

Future Vignettes: Possible Use Cases

To help education stakeholders consider how wearables, augmented reality, and virtual reality might support the creation and enhancement of responsive learning environments, five future vignettes illustrate possible use cases for applying these digital depth technologies to learning. These future vignettes represent short stories, or mini-scenarios, depicting future situations in which these technologies could be applied. They are summarized below and are then illustrated in graphic narrative format.

MentorConnect: Responsive assistance for learners

What if wearables and augmented reality could help learners navigate extended learning opportunities by connecting with mentors and coaches wherever and whenever they were needed? This future vignette assumes that schooling has shifted considerably from standalone facilities to interconnected learning ecosystems involving many community-based resources and experiences.

Learning Matrix: Digital build out closes resource gaps

What if educators could help address resource gaps by using augmented and virtual reality technologies to apply a digital layer atop unused community spaces? This future vignette imagines that educators are using these digital tools to turn unproductive or abandoned buildings such as old warehouses, shopping centers, and public buildings into venues for compelling, high-quality learning experiences.

Holistic Assessment: Authentic performance, evaluation, and reflection support deep learning

What if students could practice key social-emotional and metacognitive skills in safe virtual environments, aided by digital depth technologies? This future vignette imagines that an assessment tool powered by augmented reality, virtual reality, and wearables is providing a way for students to immerse themselves in realistic future learning and work settings while honing their collaborative and creative practices and reflecting on their performance with trusted, knowledgeable professionals.

Changing Bodies, Minds, and Policies: Deep empathy through embodying the other

What if digital depth technologies could be leveraged to create immersive narratives enabling education decision-makers to “walk in the shoes of others” in order to increase empathy for the students and families whom their decisions affect? This future vignette imagines that such experiences are helping education policymakers take more perspectives into account when developing policies.

Digital Graffiti History: Students explore their community and local heroes

What if augmented reality supported students in overlaying their perspectives on social justice issues atop their own neighborhoods? This future vignette imagines that creating digital graffiti turns students into local historians and community storytellers.

These future vignettes illustrate some possible ways in which educators and other stakeholders might usefully take advantage of wearables, augmented reality, and virtual reality to support the creation of responsive learning environments or achieve other goals. The future vignettes emphasize use cases that value positive behaviors, inclusion, and self-development. Each one starts with a brief summary describing what learning looks like in the story, lists how the technologies that we have been considering are being applied, and illustrates the future scene using a graphic narrative.

MentorConnect: Responsive Assistance for Learners

Setting the Scene

What if wearables and augmented reality could help learners navigate extended learning opportunities by connecting with mentors and coaches wherever and whenever they were needed? This future vignette assumes that schooling has shifted considerably from standalone facilities to interconnected learning ecosystems involving many community-based resources and experiences. In it, a fourth-grade student uses information from a wearable device to help surface difficulty approaching a homework assignment. A linked app reminds her that she can ask for help and helps connect her with the relevant educator when she needs support.

Key Technologies

A **smart sleeve** measures students' biometrics to gauge their responses to various activities, determining engagement, difficulty, stress; detecting fidgeting; and providing nudges to refocus.

A **smart ID badge** provides access to community resources such as libraries, maker centers, and learning hubs and performs transactions on behalf of the student. For example, it transfers money from learning accounts to providers, gathers distributed student performance data for learning records, and provides an educator support team with learners' location and task information.

A **learning assistance call button** alerts selected mentors and coaches that help is needed. An educator support team performs remote triage and provides support in a variety of media-rich formats, from simple text to real-time augmented reality conversations to virtual reality huddles.

Augmented reality earbuds reduce ambient noise and provide intimate audio for students' conversations with coaches, mentors, and counselors.



MentorConnect: Responsive Assistance for Learners



Teresa, a 4th-grade student wearing a Hello Kitty smart sleeve and matching backpack, enters the Community Media Arts Homework Center with a group of her friends. As she walks through the door, homework tasks automatically upload to her tablet, with a proposed schedule for her two hours until her grandmother picks her up.

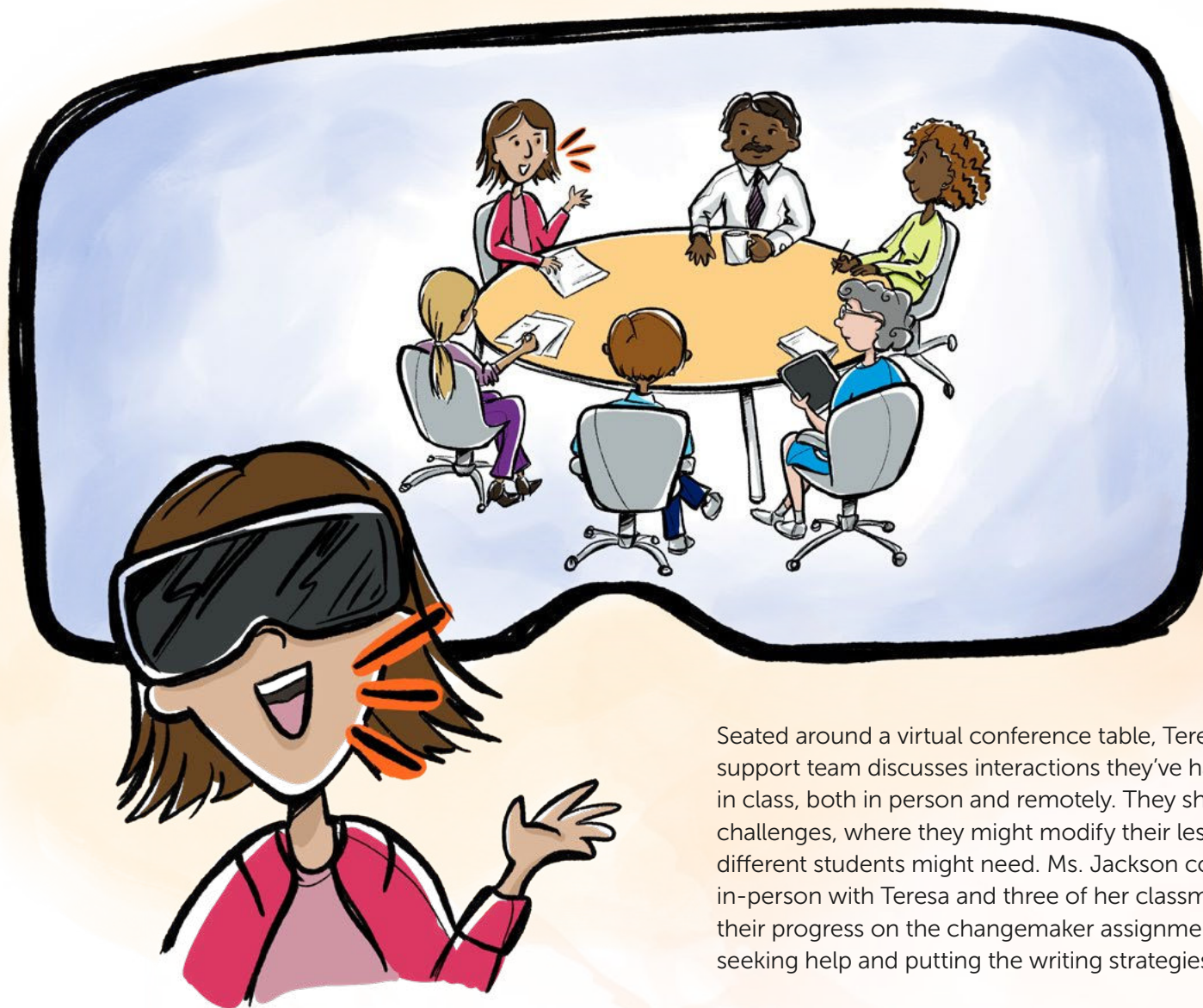


MentorConnect: Responsive Assistance for Learners



Sitting at a table with her friends, Teresa is working on her Changemaker Biography. Her friends are all heads down working on their writing assignments, but Teresa is having a hard time summarizing her notes. Struggling to start, she stares at a blank screen for more than ten minutes. As she sits, her heart rate increases, and she fidgets and squirms in her seat, triggering a nudge from the MentorConnect app. Sensing her unease, the app messages, "It's okay to ask for help, Teresa." She clicks her app icon and a holographic image of Ms. Jackson, her humanities coach, hovers in the top left corner of her tablet. Ms. Jackson's voice in Teresa's ears is clear, calm, and soothing. "Hi, Teresa. Need to chat? Walk me through your notes. Let's work through this."

MentorConnect: Responsive Assistance for Learners



Seated around a virtual conference table, Teresa's 4th-grade learning support team discusses interactions they've had with other students in class, both in person and remotely. They share stories of common challenges, where they might modify their lessons, and what supports different students might need. Ms. Jackson comments, "I'll be working in-person with Teresa and three of her classmates this week to reinforce their progress on the changemaker assignment. They did a great job seeking help and putting the writing strategies into practice."

Learning Matrix: Digital Build Out Closes Resource Gaps

Setting the Scene

What if educators could help address resource gaps by using augmented and virtual reality technologies to apply a digital layer atop unused community spaces? This future vignette imagines that educators have used these digital tools to turn unproductive or abandoned buildings such as old warehouses, shopping centers, and public buildings into venues for compelling, high-quality learning experiences. In so doing, they are helping learners access resources, learning experiences, and specialist teachers that are often not available in poor or rural schools and districts.

Key Technologies

Warehouse-scale, free-roaming virtual reality helps transform an old warehouse into a problem-solving science and innovation center. Technology upgrades, rather than a new state-of-the-art building, keep the center current.

A **virtual reality science lab** enables students to work in a completely simulated and interactive science lab using headsets and either a smartphone or a smart watch. The virtual reality lab allows students to work with potentially dangerous or expensive materials in a safe setting, to access supplemental video or visual support materials, and to interact with their teacher in real time even if she is not present in the same physical room.

Through **rockstar teacher holograms**, highly experienced, expert practitioners and specialists provide support for learning, including “hands-on” projects, expert input, lessons, lectures, panel discussions, and group learning seminars.



Learning Matrix: Digital Build Out Closes Resource Gaps



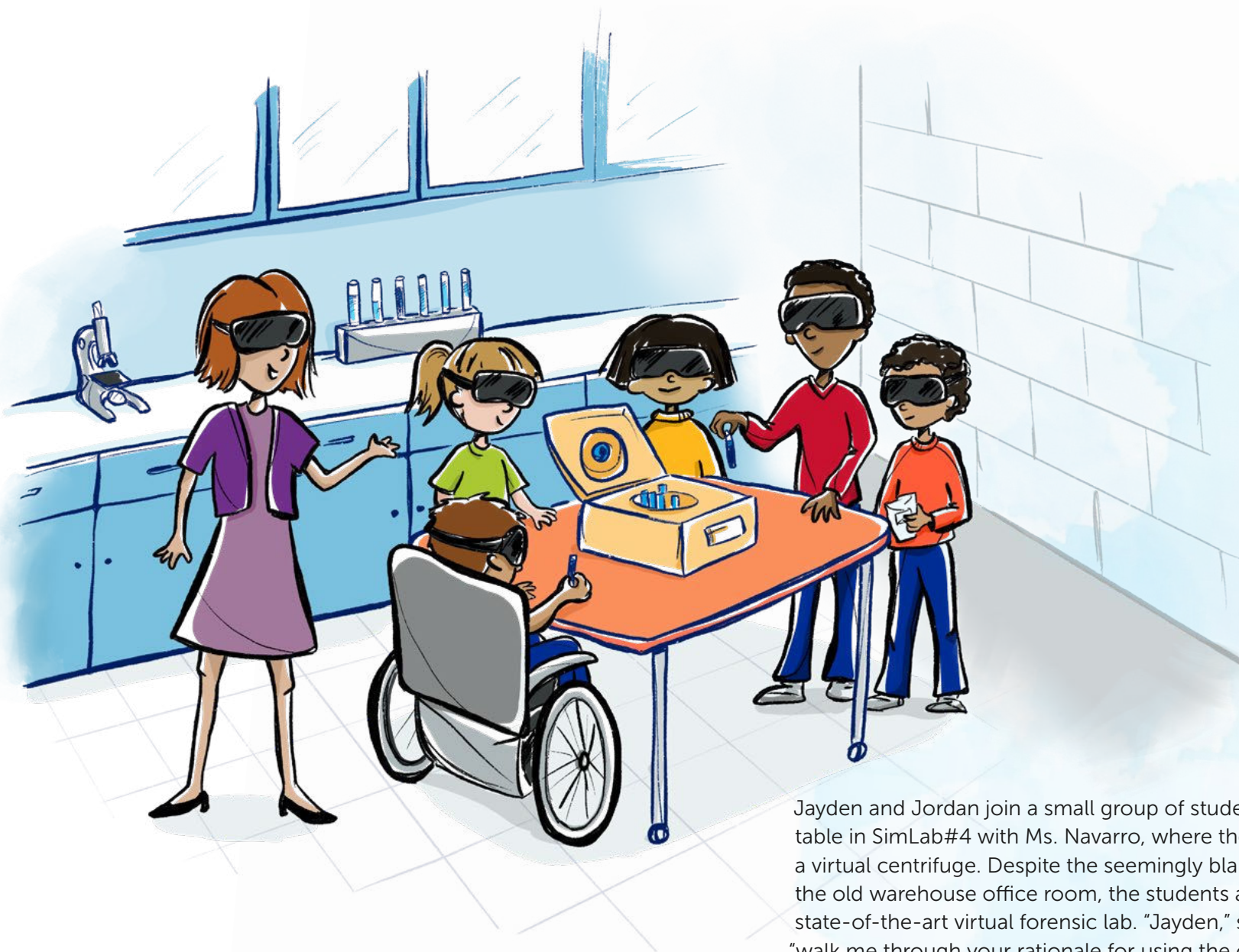
Teresa's older cousin, Jayden, walks with his friend Jordan to the Science and Innovation SimCenter. They are greeted by Mr. Jeffries, the SimFacilitator. "Hi, boys. Your teacher, Ms. Navarro, is gearing up in SimLab#4 for your lab analysis. But first you need to go to the FieldSim Arena to collect your data. Make sure you scan your badge so that the right crime scene prompts load for you. You don't want to repeat last week's project." The boys make sure the scanner reads the smart ID badges on their jacket sleeves.

Learning Matrix: Digital Build Out Closes Resource Gaps

The boys enter the FieldSim Arena, a large room where students are wearing headsets and small backpacks containing virtual reality gear. Some of their classmates have already started the crime scene data gathering phase of their DNA unit. They are roaming the arena in pairs, pointing and gesturing. As they move through the scene, audio of police radios and traffic fills their ears. They see the yellow tape and approach the crime scene. Jayden says, "Jordan, do you have the evidence checklist? I have sample containers, so you read from the checklist, and I'll collect the tissue specimens." After an hour at the virtual crime scene, the boys take off their gear and head to SimLab#4.

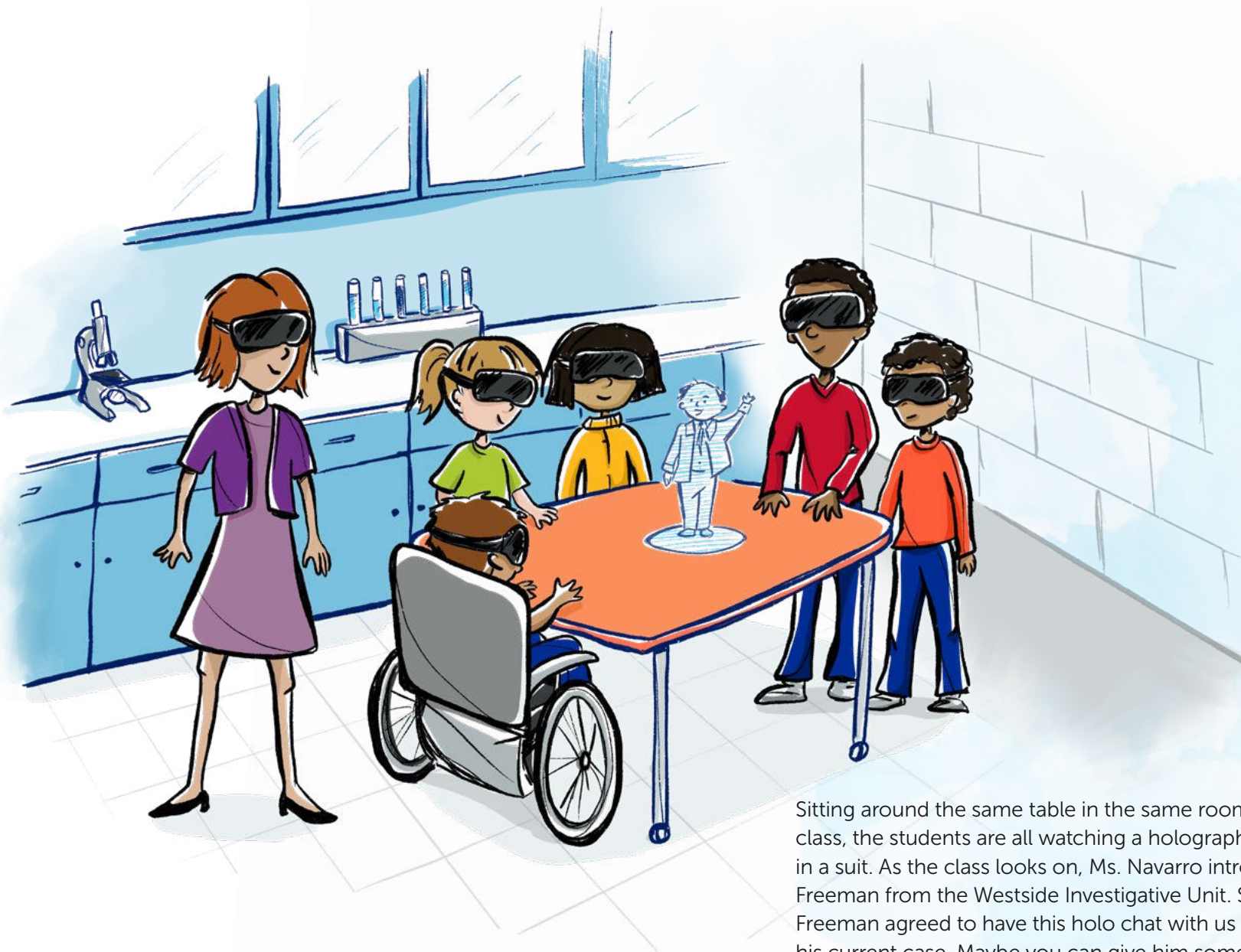


Learning Matrix: Digital Build Out Closes Resource Gaps



Jayden and Jordan join a small group of students sitting around a table in SimLab#4 with Ms. Navarro, where they load samples into a virtual centrifuge. Despite the seemingly bland surroundings of the old warehouse office room, the students are immersed in a state-of-the-art virtual forensic lab. "Jayden," says Ms. Navarro, "walk me through your rationale for using the centrifuge and tell me the next steps. At the end of lab today, I have a surprise guest."

Learning Matrix: Digital Build Out Closes Resource Gaps



Sitting around the same table in the same room at the end of class, the students are all watching a holographic image of a man in a suit. As the class looks on, Ms. Navarro introduces Inspector Freeman from the Westside Investigative Unit. She says, "Inspector Freeman agreed to have this holo chat with us and tell you about his current case. Maybe you can give him some tips."

Holistic Assessment: Holistic Performance, Evaluation, and Reflection Support Deep Learning

Setting the Scene

What if students could practice key social-emotional and metacognitive skills in safe virtual environments, aided by digital depth technologies? This future vignette imagines that an assessment tool powered by augmented reality, virtual reality, and wearables is providing a way for students to immerse themselves in realistic future learning and work settings while honing their collaborative and creative practices and reflecting on their performance with trusted, knowledgeable professionals. It reflects key dimensions of future success: mastery of core social-emotional skills and other metacognitive skills and practices that facilitate collaboration, knowledge creation, creativity and innovation. The vignette demonstrates how schools could use digital depth technologies to enable students to practice, develop and reflect on these skills in safe environments.

Key Technologies

A **collaborative augmented reality design platform** allows a group of students from different countries to work on a shared challenge. Students develop social-emotional skills and mastery of various competencies by taking on the role of professionals and applying knowledge in diverse and sometimes unfamiliar social and cultural settings.

Smart watches and smart wristbands track students' breath rates and support their self-regulation by providing reminders to take calming, deep breaths when their heart rates escalate.

Audio- and video-capture technology records the group's activities for review and assessment. The recordings are used to help enable reflection and personal growth.



Holistic Assessment: Holistic Performance, Evaluation, and Reflection Support Deep Learning

High school students Jose and Sam are gathered in a classroom where they are getting their team partners for an upcoming performance evaluation for an industrial design class. Their team members are from different countries, and they have never met. Jose shares with Sam that one of his team members, Julie, is from Ireland, and his other team member, Rafael, is from Peru.



Holistic Assessment: Holistic Performance, Evaluation, and Reflection Support Deep Learning



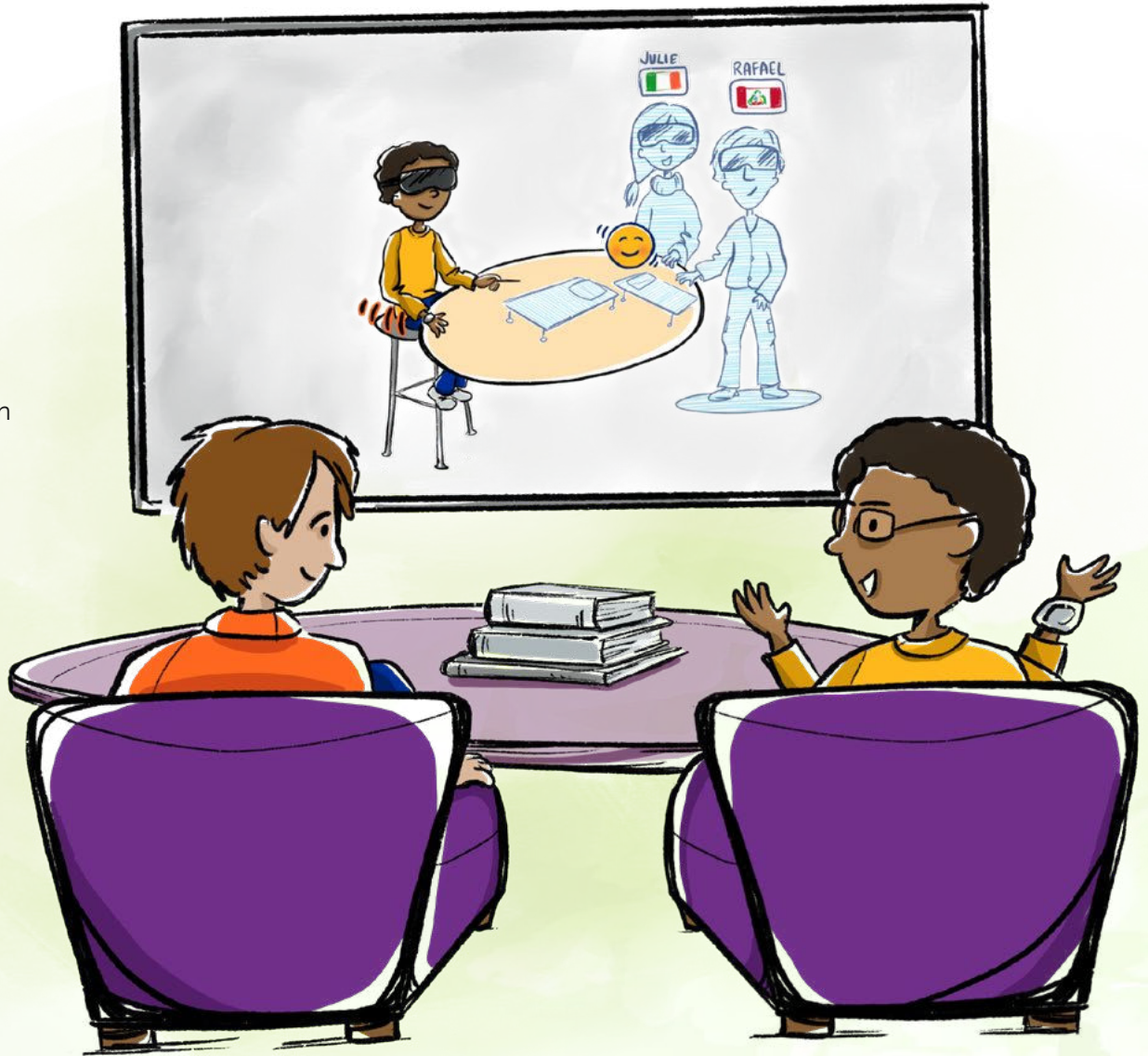
Wearing augmented reality goggles and holding a stylus, Jose points to a section of the holographic collapsible sleeper cart that he created with Julie and Rafael for homeless shelters. Julie disagrees with him about the durability of the materials that they have chosen. They only have one more week, and their project is due. Frustrated, Jose feels his smart watch pulse on his wrist, reminding him to take a moment to reframe Julie's challenge as an attempt to make their project better.



"That's a good question, Julie. Tell me what other materials might work." Julie smiles and responds, "Sure." She feels her body relax as Jose welcomes her comment rather than responding defensively. She sends Jose a smiley emoji, which hovers in the shared design space."

Holistic Assessment: Holistic Performance, Evaluation, and Reflection Support Deep Learning

Jose is reviewing the audio and video of his project design session with his mentor, Alex. Seated in a comfortable lounge area reviewing a screen, Jose and his mentor Alex are reviewing audio and video from Jose's project design session. While making comments about what parts of the collaboration were difficult, Alex points out where Jose regulated his emotions well and how he might improve his collaboration skills. He asks, "What strategy did you use here when Julie challenged your choice of materials?" Jose replies, "I felt my body tense up. That's when I got the wrist nudge to breathe. That reminded me to stop and think about Julie. She is a team partner, so she is only trying to make our project outcome better." Alex replies, "Good reflection and regulation, Jose."



Changing Bodies, Minds, and Policies: Deep Empathy through Embodying the Other

Setting the Scene

What if digital depth technologies could be leveraged to create immersive narratives enabling education decision-makers to “walk in the shoes of others” in order to increase empathy for the students and families whom their decisions affect? This future vignette imagines that such experiences are helping education policymakers take more perspectives into account when developing policies. In so doing, it addresses the challenge that, despite well-intentioned policies, many aspects of the U.S. educational system remain poorly aligned with the realities of students and their families. The vignette explores the potential for well-designed immersive narratives to increase opportunities for empathy and perspective-building among administrators and policy makers, leading to more compassionate, equitable policies and institutional requirements that can help support increasingly diverse student communities.

Key Technologies

Immersive virtual reality narratives support embodiment of other identities, helping district- and school-based decision makers and legislators understand issues such as poverty and racial bias from a first-hand, embodied perspective. Such experiences are used to inform more user-centered policies and programs.

Artificial intelligence (AI) programmed into the virtual reality system works with devices in the physical room, such as wearables and sensors, to make the user’s embodied experiences more realistic. For example, the artificial intelligence adjusts temperature controls and alters the volume of a virtual character’s voice in response to the user’s stress levels.

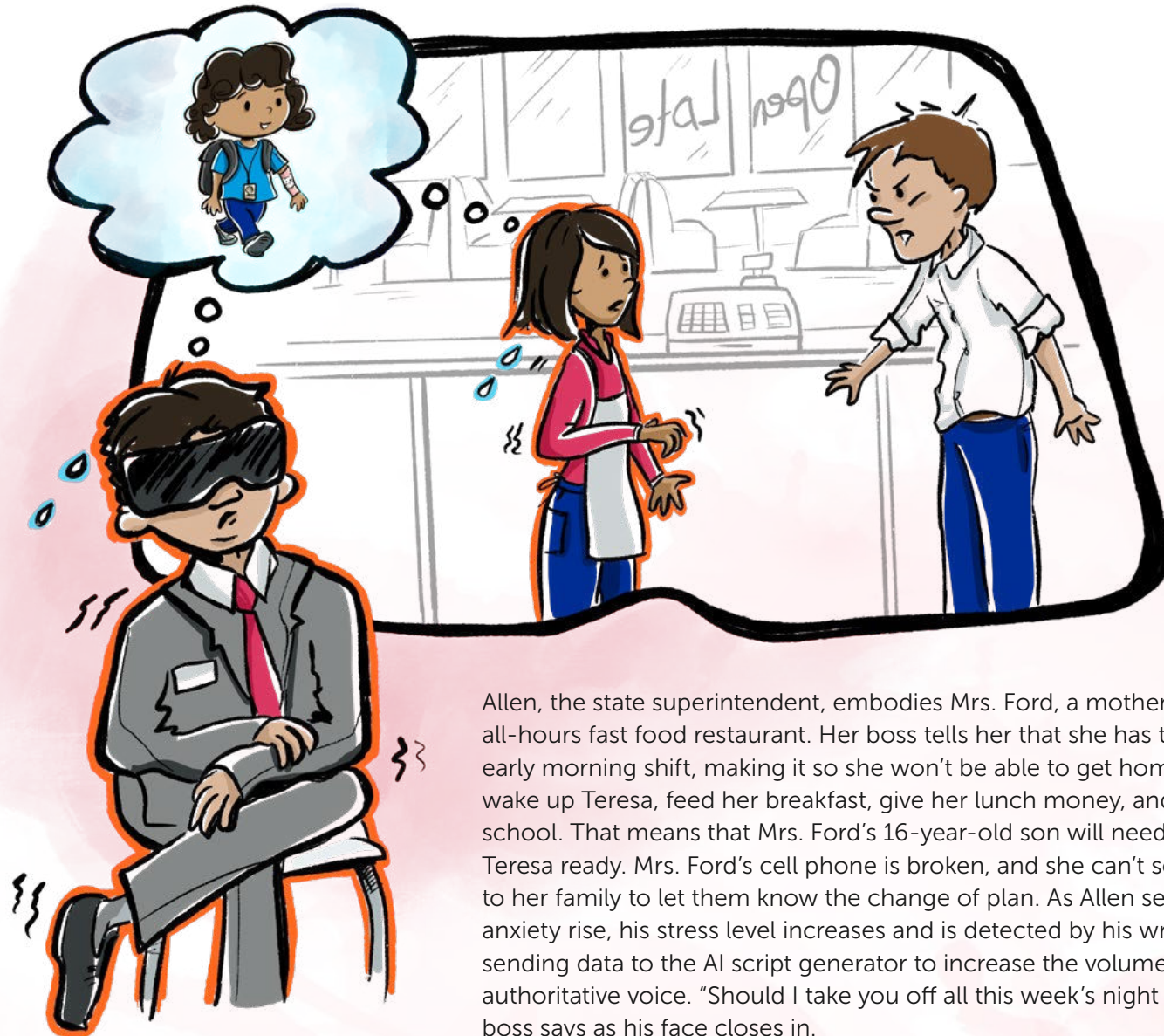


Changing Bodies, Minds, and Policies: Deep Empathy through Embodying the Other

"Welcome to this year's experience learning summit!" Governor Mirano announces from her podium inside the Experience Arena. "This year, we want you to feel what it is like to make the kinds of everyday choices that our students and parents have to make. The scenes you are about to experience are based on true stories and comments contributed by hundreds of parents and students across our districts in partnership with our policy team."

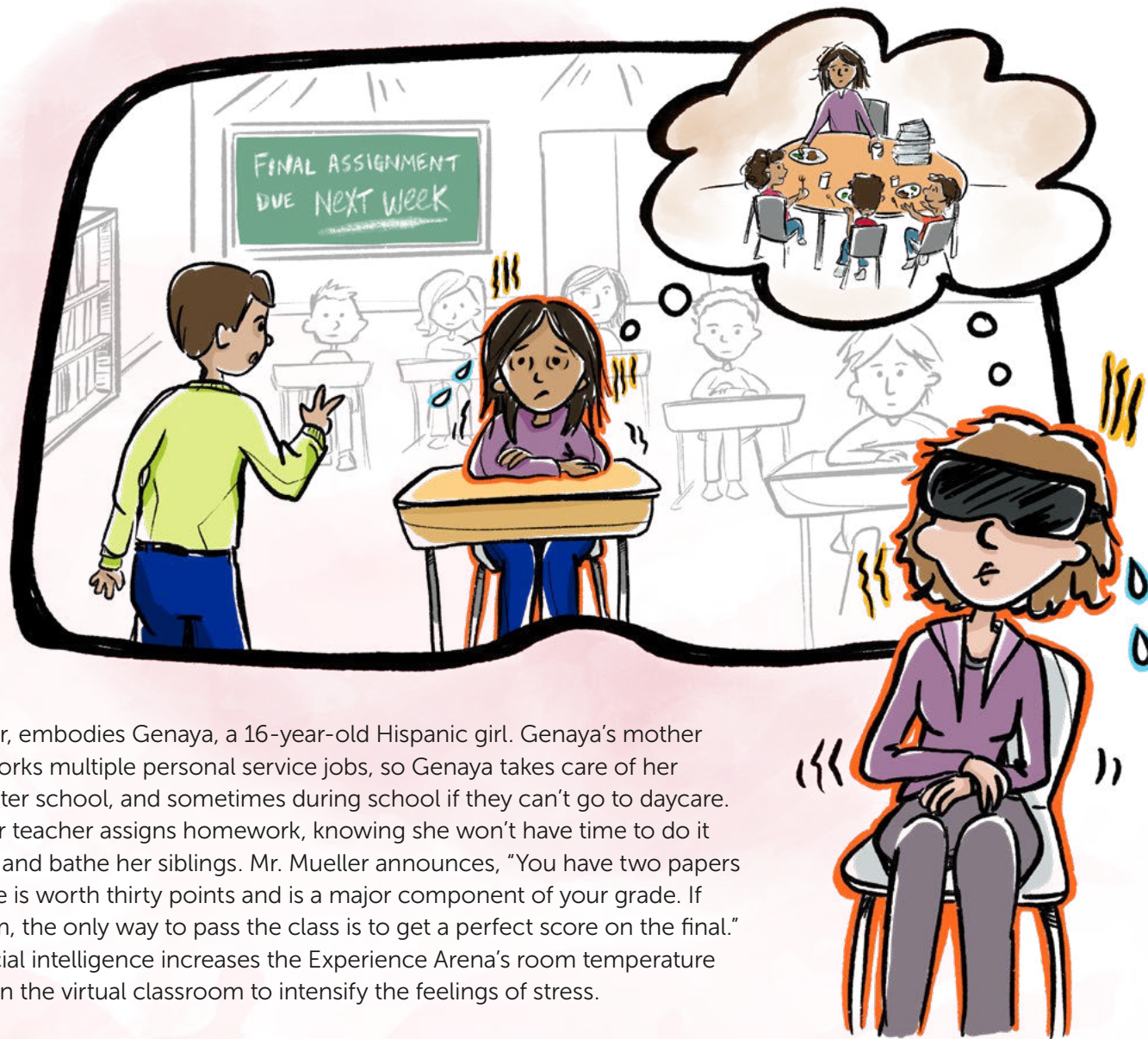


Changing Bodies, Minds, and Policies: Deep Empathy through Embodying the Other



Allen, the state superintendent, embodies Mrs. Ford, a mother working at an all-hours fast food restaurant. Her boss tells her that she has to cover the early morning shift, making it so she won't be able to get home in time to wake up Teresa, feed her breakfast, give her lunch money, and take her to school. That means that Mrs. Ford's 16-year-old son will need to help get Teresa ready. Mrs. Ford's cell phone is broken, and she can't send a message to her family to let them know the change of plan. As Allen sees Mrs. Ford's anxiety rise, his stress level increases and is detected by his wristband, sending data to the AI script generator to increase the volume of the boss's authoritative voice. "Should I take you off all this week's night shifts?" the boss says as his face closes in.

Changing Bodies, Minds, and Policies: Deep Empathy through Embodying the Other



Paulette, a state legislator, embodies Genaya, a 16-year-old Hispanic girl. Genaya's mother is undocumented and works multiple personal service jobs, so Genaya takes care of her three younger siblings after school, and sometimes during school if they can't go to daycare. She sits in class while her teacher assigns homework, knowing she won't have time to do it because she has to feed and bathe her siblings. Mr. Mueller announces, "You have two papers due next week. Each one is worth thirty points and is a major component of your grade. If you don't complete them, the only way to pass the class is to get a perfect score on the final." The virtual reality's artificial intelligence increases the Experience Arena's room temperature and brightens the lights in the virtual classroom to intensify the feelings of stress.

Changing Bodies, Minds, and Policies: Deep Empathy through Embodying the Other



After their virtual reality experiences, Paulette and Allen are sitting with other policy makers. Together they engage in a roundtable discussion, sharing the insights they have gained by embodying the experiences of others. Allen says, "A parent should never have to worry that her child might go hungry while in school. And kids should never feel ashamed." "Yes," Paulette replies, "I'm seeing our work as policy makers from a new vantage point. Our policies should be driven by understanding and compassion for our students and respect for their changing responsibilities, not by a quest for efficiency and rigid rules." Allen replies, "Or at least we should remember the unintended consequences of our work."

Digital Graffiti History: Students Explore Their Community and Local Heroes

Setting the Scene

What if augmented reality supported students in overlaying their perspectives on social justice issues atop their own neighborhoods? This future vignette imagines that creating digital graffiti turns students into local historians and community storytellers. In it, three-dimensional overlays of text, images, and video embellish neighborhood places and people into a living history book that supports present-day social justice actions. By helping students make personal connections to curriculum, the augmented reality tools that the vignette portrays help make learning relevant and inspire intrinsic motivation for students to pursue challenges and internalize learning.

Key Technologies

Augmented reality authoring tools allow students to create location-based triggers that tag places with local user-generated digital content such as student interviews with neighborhood residents, archival images, historical data, current events, video, and audio.

A wearable navigator downloads tours onto mobile devices, wearable insoles, or smart watches to support students in navigating local histories.

Augmented reality tours and treasure hunts of local neighborhoods blend Pokémon Go-like games with locally written histories to provide ubiquitous learning experiences that can help reduce summer learning losses.

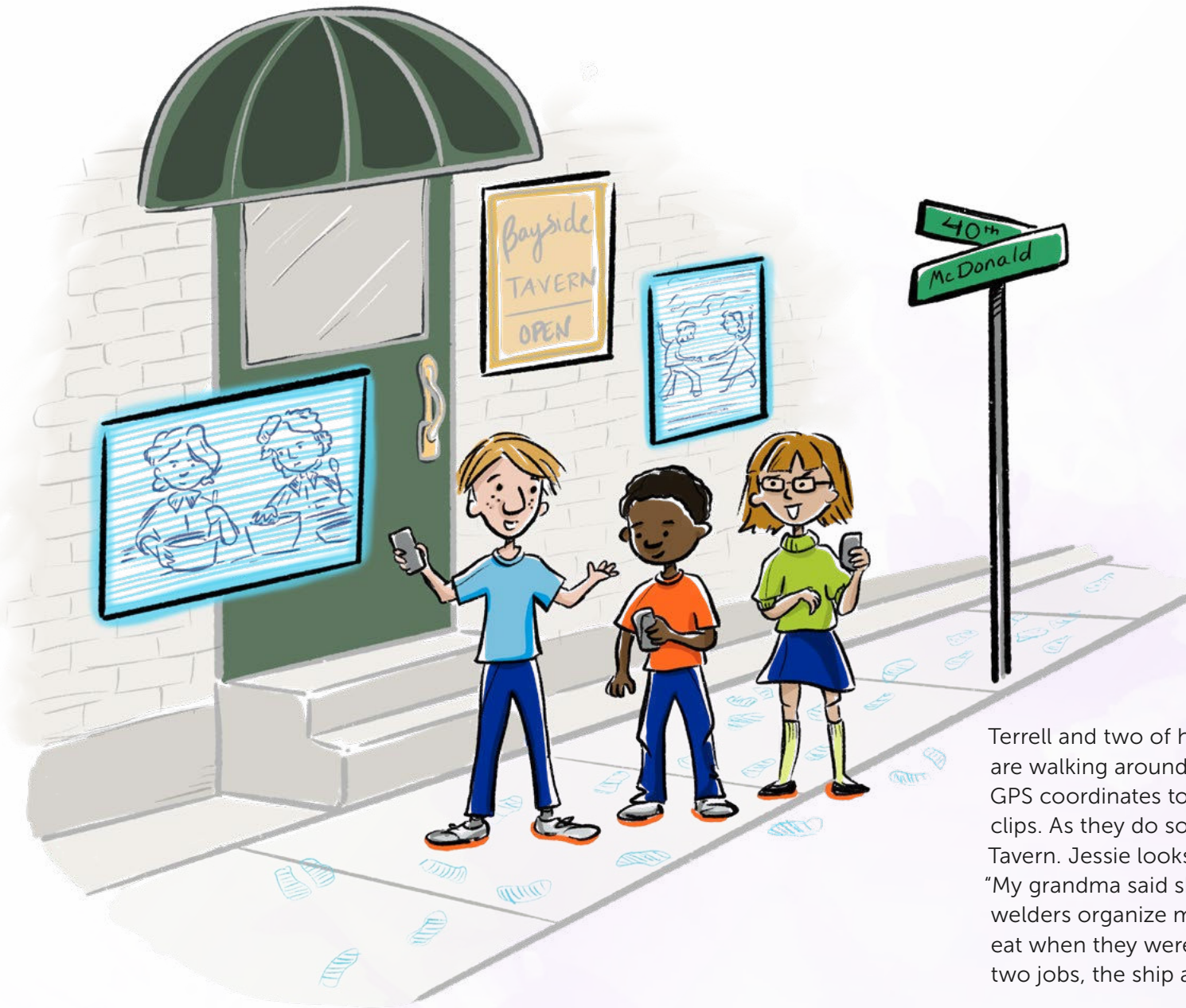


Digital Graffiti History: Students Explore Their Community and Local Heroes

6th-grader Terrell is sitting with his grandfather. They are looking at a photo album of his grandfather welding in the engine room of a Liberty Ship in Richmond, California. "Granddaddy, who worked with you as a welder on the ship? Did they all come from Georgia like you? How much did you get paid, and what did you do for fun after work?" "One question at a time," his grandfather said. "You know that old tavern on the corner of 40th and Mac-Donald Avenue? We danced there on Friday nights. But we also talked about who were the good union bosses willing to help welders get additional work shifts."



Digital Graffiti History: Students Explore Their Community and Local Heroes



Terrell and two of his classmates, Jessie and Adam, are walking around their neighborhood, capturing GPS coordinates to tag with images and audio clips. As they do so, they come to the Bayside Tavern. Jessie looks at Terrell and Adam, saying, "My grandma said she helped the other women welders organize meals so that their families could eat when they were still working. She said they had two jobs, the ship and the family!"

Digital Graffiti History: Students Explore Their Community and Local Heroes

In a 6th-grade classroom at Richmond Middle School, Miss Johnson makes an announcement before starting her humanities class. "I want to share with you all something I saw in my local newsfeed this morning. Thanks to all of your hard work with the local heroes assignment, the California Historical Society listed the Richmond Digital Graffiti Tour in their list of top-ten must-do living history walks in the area. They messaged me and are willing to help us curate the tour and develop more interactive experiences with your stories."



Insights and Implications

As the future vignettes illustrate, there is considerable potential for wearables, augmented reality, and virtual reality to help educators create more responsive teaching and learning environments that increase student engagement and personalization of learning, foster learners' and other stakeholders' understanding of themselves and of others' experiences and perspectives, and aid in the development of critical thinking. However, there are also cautionary points that education stakeholders need to consider in evaluating these technologies' potential to support learning objectives in specific settings. Some insights and implications, both positive and negative, are explored further below. To make best use of wearables, augmented reality, and virtual reality in education, stakeholders need to:

Support Individual Agency through Intentional Reflection

Data gathered from wearables and recordings of immersive collaborative sessions can provide learners, educators, and other stakeholders with a rich picture of their own performance, behaviors, and patterns in support of reflection for personal growth. Students may learn new things about themselves as they come to see patterns in their responses to various situations across academic and social domains. Ensuring that students have the opportunity to reflect with a trained coach or educator will help support them in developing such self-awareness. Such reflection could become a central part of teaching and learning practice.

Ensure Equitable Access

Given the power that wearables, augmented reality, and virtual reality have for supporting learning, it is vital that all students have appropriate access to these technologies. Policies and other measures should be put in place to ensure that students in under-resourced environments have the same level of exposure to digital depth technologies as those in better-resourced environments. Without such measures, there is a risk of increasing existing inequities and widening the digital divide between students in well-resourced schools and those in struggling schools.

Use Digital Build Out as a Strategy for Flexible Adaptation

A digital build out is a strategy that involves making use of digital depth technologies in place of physical infrastructure. Augmented reality can enhance most geographies, turning even unlikely places into living museums, history books, and classrooms. Virtual reality can create virtual science labs, arts rooms, and performance spaces.

Despite these possibilities, choices around digital build outs must be made with equity in mind. A digital build out can reduce fixed costs since software and technology upgrades replace new building and infrastructure. It can also increase flexibility in adapting as technology tools and learning-related needs change. However, a digital build out strategy may exacerbate equity gaps and increase the digital divide for districts or schools that lack even basic resources. For those considering a digital build out, careful consideration of both its advantages and disadvantages versus investment in physical infrastructure will be needed.

Provide Appropriate Professional Development

The digital depth enabled by wearables, augmented reality, and virtual reality can bring a new dimension to learning environments. Maximizing that potential will require thoughtful investment in educator professional development. Equitable access to high-quality training and professional development is critical for supporting teachers in their efforts to utilize these new technologies to enhance and expand their teaching. Educators will need exposure, time, and training in order to develop an understanding of how best to employ them. However, not all teachers need to become experts in these technologies; it may be increasingly useful to consider how specialized instructional technology roles might help guide their use within and across learning environments. Schools, school districts, and other places of learning without funds for professional development may not achieve the potential benefits for their students, creating or exacerbating gaps in access to high-quality learning experiences.

Treat Curriculum Development as Learning Environment Design

Wearables, augmented reality, and virtual reality offer new tools for embedding learning into diverse kinds of spaces and experiences. As educators consider their curriculum goals, they need to assess how these technologies might support learning outcomes and enable the creation of learning environments that scaffold learning toward those goals. Educators and schools that use these technologies successfully will shift curriculum development to include learning environment and experience design, potentially creating new roles, departments, and partnerships.

Develop a New Horizon for Assessment

Wearables, augmented reality, and virtual reality allow for unprecedented opportunities to create meaningful simulations that can enable students to perform as practitioners and receive rich feedback. They could provide opportunities for students to show what they know and who they are becoming as learners and practitioners. These technologies could also help capture new kinds of data (including social-emotional as well as academic and metacognitive data) that could support productive reflection with students. They could help assessment become more integrated into the practice of teaching and learning. Wearables, augmented reality, and virtual reality could also support competency-based assessment in evolving beyond its current primary focus on academic attainment into a richer and deeper reflection on personal growth and maturity.

Set Clear Expectations around Data Privacy and Ownership

Given the amount of personal data that wearables, augmented reality, and virtual reality could collect, policies about the appropriate use of data and privacy protections must be clearly articulated. Addressing concerns about data privacy and ownership will involve establishing data security strategies; setting protocols for data access and sharing within and beyond a particular learning environment; and communicating with students, families, and educators about privacy protections. Clarifying data ownership rights among students, schools, and technology companies could prove particularly challenging.

Use Insights from Developmental and Brain Science to Guide Technology Use

We now know that the human brain is “plastic,” meaning that its neurological wiring can adapt and change according to events and environmental conditions. The adolescent brain in particular undergoes a significant amount of restructuring. It is important that this plasticity be supported for healthy psychosocial development, not undermined by poorly designed technological experiences.² While the freedom and creativity of augmented and virtual realities can allow for a wide range of exploration, education stakeholders must ensure that experiences using these technologies are designed in developmentally appropriate ways. Exposing young elementary children, middle schoolers, or older teens to potentially violent or harmful situations may be damaging to healthy brain development and can lead to anti-social behaviors.³ In addition, disorders such as obsessions with personal data or virtual worlds could develop, leading to unproductive rather than supportive habits.

Ensure Safety in Digital Spaces and Virtual Environments

Wearables, augmented reality, and virtual reality allow for new levels of digital interaction. One of the downsides to such a development is that cyber-bullying and other forms of abuse could also take on new and more extreme forms. For example, students could use the immersive, connected capabilities of these technologies to harass others, making them feel uncomfortable and possibly compromising their privacy or safety. As with data privacy and ownership, clear and consistent policies will need to be put into place to help mitigate the potential for harassment in learning environments that make use of these technologies.

Support Compassion-Driven Policies, Practices, and Systems

As learning environments enabled by wearables, augmented reality, and virtual reality become more seamless and integrated with existing learning experiences, there will be more opportunities to have consistent, visible reminders of different points of view. Wearables can provide a deeper understanding of the barriers to learning for individuals, including factors outside of the classroom. Augmented reality can layer physical places with data, adding a

sense of context and perspective to environments. Immersive virtual reality narratives have the potential to scale and measure empathy in ways that we have not seen before. For an education system that is structurally biased, digital depth technologies may offer effective opportunities to begin to create more widespread understanding across socio-economic and racial demographic groups.

Avoid Using New Technology in Old Ways

Wearables, augmented reality, and virtual reality offer educators the ability to create engaging student-centered learning experiences that truly enhance teaching and learning. These technologies also run the risk of being used to deliver old approaches in new ways; for example, they could support the creation of canned experiences that represent simply the next iteration of mass-marketed curriculum. Such powerful technologies can and should be utilized by educators to create responsive learning environments that optimize learning, not as a means of making education more efficient.

Keep a Human-Centered Frame

The true catalyst of any change is not technology, but the human at the center. While wearables, augmented reality, and virtual reality can surface new data and insights about barriers to learning, an abundance of data regarding underserved student needs currently exists and is not being fully utilized to improve education systems. Similarly, these technologies can assist in cultivating social-emotional skills such as empathy, but many opportunities for people to understand others' experiences already exist. The desire to become more empathetic must start with the person and the expectations and culture of a learning environment. As these examples indicate, no technology on its own can be a change agent.

Conclusion

Digital depth has the potential to create environments that respond to and support core social-emotional skills and cognitive and metacognitive capacities. It offers ways to scale opportunities for learners to develop practices and behaviors such as empathy, perspective taking, critical thinking, and self-awareness that will support their personal, academic, and professional lives. For education to make full use of digital depth technologies, careful consideration should be paid to how wearables, augmented reality, and virtual reality are used at the individual, classroom, and system levels. Through careful consideration of the potential these technologies hold for learning and how they might be implemented, education stakeholders can take the lead in shaping their uses, impacting learning in significant ways.

Leveraging Digital Depth

This paper has explored ways in which wearables, augmented reality, and virtual reality add digital depth to our physical experiences, potentially supporting the creation of responsive learning environments characterized by immersion, embodiment, contextualization, and self-awareness. Below are some suggestions for exploring these technologies' potential in your setting.

1. Make a Commitment to Developing First-Hand Knowledge

Wearables, augmented reality, and virtual reality applications can be confusing and hard to understand without trying them yourself.

- A** Develop a plan with colleagues to test out a range of applications and experiences so that first-hand experiences contribute to your assessment of how digital depth tools might help create more responsive and positive learning environments. Whether you form a group of volunteers to try out a new wearable for three months, download the Google Cardboard software and content, or take an outing to a virtual reality theme park or lab, experiment as broadly and frequently as you can. These technologies and their applications are changing fast.

- B** As you explore, create a way to keep track of what you and your colleagues experience and your thoughts about its potential value.

- C** Consider also how you might involve students in sharing their ideas about and experiences with wearables, augmented reality, and virtual reality.

2. Explore Key Learning Design Questions

Given that applications of wearables, augmented reality, and virtual reality tools and platforms should be considered with distinct learning goals in mind, deep consideration needs to be given to how immersion, embodiment, contextualization, and self-awareness might help create learning environments and experiences that address specific learning goals. Key learning experience design questions include:

- A** In which activities and practices might personal feedback enhance students' self-knowledge and agency and influence their performance?

- B** Which complex concepts, intellectual frameworks, and collaborative settings might benefit from rich visualizations?

- C** How might richer contextualization make specific learning goals more relevant to students?

- D** How might experiences that enable immersion and embodiment support the development of perspective taking, empathy, and social-emotional skills?

Answering these questions as you evaluate the potential of digital depth technologies can help you ensure that your ultimate uses of them support specific learning goals.

3. Evaluate How Digital Depth Technologies Might Extend or Leverage Resources

Augmented and virtual reality applications can create simulated resource environments such as labs and museums. They can also create shared hybrid or digital spaces for collaborative exchanges. While these technologies may not be permanent, they can provide interim solutions to costly facilities decisions, providing more time to understand needs and priorities. In the context of your setting, explore these questions related to their potential to help you extend or leverage resources:

- A** How might an augmented reality application or virtual reality platform help extend and leverage the contributions of the educators or other adults in your setting?

- B** How might augmented reality tools or virtual reality platforms provide access to human resources (such as specialist teachers, experts, or professional practitioners) that would otherwise be inaccessible?

- C** What kinds of costly physical resources (for example, labs, art and music studios, museums, or field trips) might be enhanced or simulated with augmented and virtual reality tools?

4. Consider Ways that Digital Depth Technologies Might Enhance Teacher and Administrator Professional Development

Digital depth technologies can benefit adults as well as students. Wearables, augmented reality, and virtual reality can be leveraged to enhance and extend teacher and administrator professional development. Possibilities and questions to consider for each of these technologies appear below.

- A** Wearables can offer teachers and administrators the chance to collect performance data on themselves, giving insights into factors such as their emotional states that can help them develop greater levels of self-awareness. How might such insights be used to give teachers and administrators more personalized feedback and professional development?

- B** Augmented reality can turn the world into an information-rich learning environment. How might educators enrich their collaborative professional spaces within and outside school with information, data, and media that help educators support one another in improving their practice? For example, what might a Pokémon Go for education professional development look like? What other applications can you imagine?

- C** Shifting perspectives and identity through embodiment can be a powerful experiential benefit of virtual reality. How might such experiential learning be leveraged by teachers, administrators, or policy makers in your region? Are there key issues that might be best addressed through some kind of virtual experience that enables all participants or stakeholders to test their assumptions and shift their perspectives?

5. Ask Yourself How Digital Depth Technologies Might Provide Environments That Help Students Show Their Learning More Robustly

Keep in mind that digital depth technologies are not exclusively content-consumption experiences; they can also be rich authoring tools. Consider how you might use them for this purpose. For example:

- A** How might students use wearables to make the invisible aspects of their learning process more visible to them?

- B** Similarly, how might students use the personal data captured by wearables to inform their understanding of their own performance, such as times when they felt anxious or stressed, and successful strategies that helped them overcome such distracting emotions?

- C** How might the authoring and tagging capabilities of augmented reality tools help students create performances and interactive exhibits that demonstrate their learning?

- D** How might students employ the world building aspects of virtual reality to solve problems, present information, and display mastery of concepts?

Appendix

About the Authors

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Andrea Saveri of Saveri Consulting makes the future actionable for clients through research-based foresight, visual maps, forecast artifacts, and highly creative engagement experiences. She partners with clients to create clear strategic pathways to transformation and resilience in a highly complex world. Andrea is a graduate of Harvard University and the University of California at Berkeley.

Katherine Prince leads KnowledgeWorks' exploration of the future of learning. As Senior Director, Strategic Foresight, she speaks and writes about the trends shaping education over the next decade and helps education stakeholders strategize about how to become active agents of change in shaping the future. Katherine holds a BA in English from Ohio Wesleyan University, an MA in English from the University of Iowa, and an MBA from The Open University and is a member of the Association of Professional Futurists.

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