Audience-Guided Immersive Learning Experience (AGILE)

Ryan Stroupe, Construction Engineering Research Laboratory,
U.S. Army Corps of Engineers

ABSTRACT

The intent of this research project is to demonstrate that instruction with immersive training environments produces better learning outcomes for students and other societal benefits. This online, self-paced teaching approach allows students to work through real-world problems, eliminating the costs and emissions associated with travel to a central facility, which is critical as our students are spread across twelve time zones.

Immersive training, already familiar to airline pilots and healthcare workers, increases knowledge gain, extends skill retention, and engages students more effectively than conventional remote instruction like recorded PowerPoint-based lectures. This approach delivers similar outcomes to in-person labs while being highly accessible to remote students and is endlessly adaptable to different lesson types.

The target audience for our training is energy managers at large federal installations who oversee hundreds of facilities and are responsible for ambitious energy and building performance goals. Our immersive environments recreate the mechanical rooms where they work by using 3D panoramic photos from actual sites or computer simulations. In these models students complete exercises focused on existing building commissioning (EBCx) skills. The immersive models are complemented by training tools that collect student responses, allowing us to validate understanding and measure the coursework's success. After completing the EBCx training series, students are better prepared to manage commissioning services provided by third parties and perform some of the work themselves.

This paper describes the process to be used to evaluate and compare our immersive instruction with conventional online learning techniques, details our content development process, and demonstrates several specific teaching units.

Introduction

Problem Statement

Mechanical systems account for a substantial portion of facility energy use; according to the Energy Information Administration (EIA), HVAC systems alone represent approximately 40% of commercial building energy consumption (EIA 2018). Consequently, optimizing these systems through Existing Building Commissioning (EBCx) is one of the most cost-effective strategies for achieving enterprise-wide energy reduction targets. EBCx, a quality control process focused on fixing and optimizing rather than replacing equipment, typically produces a return on investment in less than one year and yields median whole-building energy savings of 16% (Crowe et al. 2020; Mills et al. 2005).

Despite these clear energy efficiency outcomes, scaling EBCx across large, distributed portfolios like the Army's Installation Management Command (IMCOM) presents a significant challenge. EBCx projects require highly skilled facility staff capable of diagnosing complex mechanical issues. Developing these operational, field-based skills through conventional classroom instruction has limited efficacy. (Fedesco, Cavin, and Henares 2020; Hou et al. 2017). While learning laboratories and physical practicums provide the necessary hands-on exposure, they are heavily constrained. Physical labs limit training access to geographically local staff or incur high travel costs. Physical labs are expensive and difficult to reconfigure. Because every facility is a custom project with an abundance of unique HVAC configurations, a physical lab built around a single system cannot provide the variation required to fully prepare energy managers for the range of facility types and operational disfunction they will encounter over their careers. Ultimately, a reliance on unscalable physical training environments creates a bottleneck that limits the deployment of EBCx, leaving significant energy savings unrealized.

Training Audiences and Learning Platforms

To bridge this gap and accelerate energy efficiency outcomes, a more accessible and comprehensive teaching solution is required. Audience-Guided Immersive Learning Environments (AGILE) solve the constraints of physical laboratories by providing online, scalable access to an abundance of technical teaching scenarios. Within these environments students can navigate independently, zoom in on specific equipment details, take measurements, identify energy saving opportunities, and develop diagrams as if they were in actual mechanical rooms. While immersive learning has been successfully applied to train pilots, nurses, and industrial operators (Alfyananda et al. 2023; Wen-Der et al. 2022), its application in the training of energy managers remains underutilized.

Our work focuses on leveraging AGILE to instruct the energy managers and maintenance staff operating Army facilities. Since 2016, the US Army Corps of Engineers (USACE) has supported a 9-month web-based training series for IMCOM staff focused on EBCx skills. Historically, this series relied on static photos, videos, and a week-long in-person practicum. By transitioning to a simulated, immersive learning approach, remote students are exposed to a myriad of virtual mechanical systems and degradation faults including equipment scenarios similar to ones that exist at their home installations. This approach is more cost effective than utilizing a single laboratory building where students would travel and will produce better learning results than traditional on-demand instruction. The goal is to dramatically improve the ability of IMCOM facility staff to manage energy consumption and optimize the operation of federal facilities by empowering them with scalable, immersive EBCx trainings.

Army and other federal agency installation Energy Managers serve as the primary audience for our immersive models and teaching content. Their locations at Army bases and other facilities around the globe and in various time zones encouraged us to embrace on-demand based instruction. Figure 1 maps student locations for our current training cohort taking place in 2026.

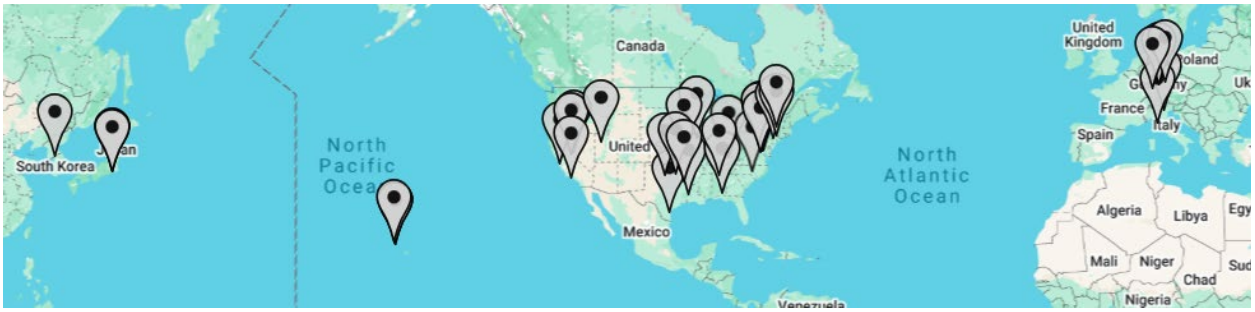

Figure 1. 2026 EBCx Academy student installation locations

Our federal agency students are typically exposed to our immersive training content after it is initially developed and therefore serve as beta testers and sources of constructive feedback. The regular, weekly cadence of our course prevents this audience from being ideal candidates for our content testing process since all the necessary pieces (pre- and post-tests, finalized conventional training content, and finalized immersive training content) are not in place when a new course begins. Additionally, we prefer to emphasize the immersive model approach with these students and would have a difficult time creating a control group willing to be limited to traditional instruction as part of this training effort.

To develop the necessary test and control groups for this study, we are partnering with the Building Commissioning Association (BCxA), a nonprofit organization made up of commissioning providers and other building specialists. BCxA member firms will provide us with a pool of students made up primarily of emerging commissioning professionals eager to benefit from these skill-focused trainings. We intend to gather additional test participants through the Whole Building Design Guide (WBDG), a website managed by the National Institute of Building Sciences (NIBS). The WBDG web site is also the intended, publicly available platform through which our training content will reach thousands of additional learners.

Because of security concerns, the federal employees that represent our students cannot access our content on public servers like WBDG. For these students our materials are staged through Microsoft TEAMS channels. The intent is to use WBDG, Microsoft forms or other online tools for pre- and post-testing. Ultimately, we will host all content and testing on WBDG, so BCxA study participants and others from the public can access everything from one platform.

3D Immersive Environments

The immersive training will utilize a combination of virtual 3-D environments and simulated software interfaces. Virtual 3-D environments will be developed for mechanical rooms, electrical rooms, ceiling plenums, facility rooftops, and building spaces. Models will be developed using photos of actual sites or computer simulations of imagined facilities. Students will be able to navigate around these models, identify different equipment types, read equipment nameplates, develop diagrams, and identify operational problems.

This project depends on the use of several mature software programs and tools. SketchUp, a 3-D modelling program, is used to create mechanical rooms and building spaces at imagined facilities. 3Dvista is used to create navigable environments from SketchUp models or site photos of actual facilities. Figure 2 shows 3Dvista virtual environments developed from site photographs. Figure 3 shows 3Dvista virtual environments developed from SketchUp models.

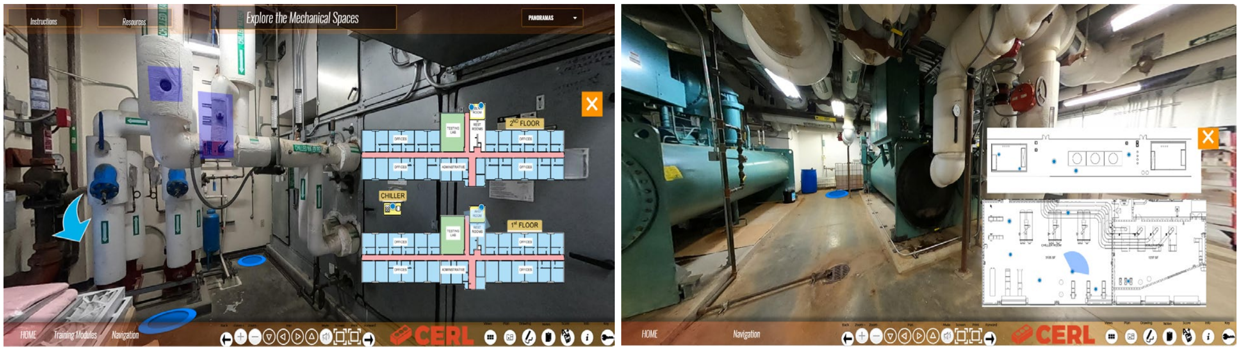

Figure 2. Examples of virtual envionments developed from real spaces using site photos and 3DVista

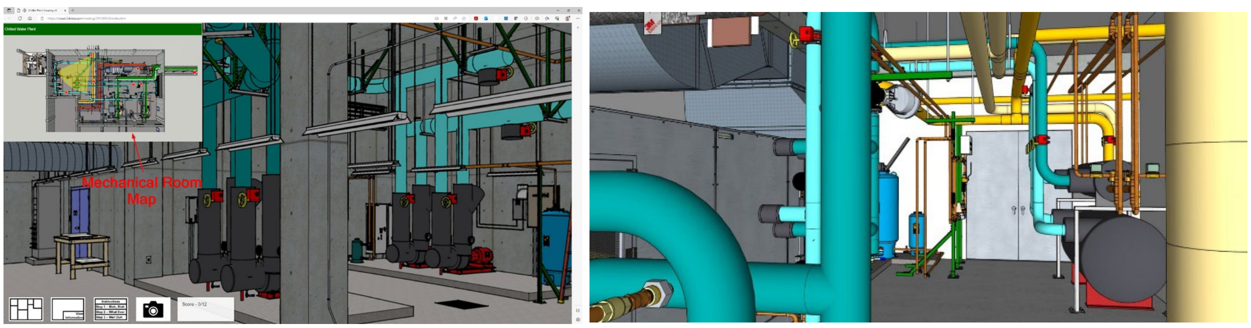

Figure 3. Examples of virtual envionments developed from SketchUp models and 3DVista

WBDG will be used to host additional content and student performance evaluations. Evaluations will allow us to 1) test students using immersive learning tools and see how their performance compares to students exposed to more conventional instruction and 2) determine the limitations that exist with our immersive learning approach. In addition to the immersive 3Dvista environments, support content will be developed using Microsoft forms, PowerPoint shows, and third-party web sites. By separating the instructional content and testing from the models, it allows us to easily link and update these resources without necessitating regular edits to the immersive environments.

In addition to virtual models of physical spaces, this project will include simulated software interfaces developed around building controls for HVAC and lighting systems. Students will be able to navigate around the simulated building control platforms in exactly the same way as actual control interfaces, moving from screen to screen, and clicking on hot links to find additional details. Students will learn how to set up trends, adjust control setpoints, find issues, and execute functional tests. Simulated interfaces will also be developed around the use of specific software tools for building benchmarking, chart making, and energy saving calculations.

Training Content Development and Testing Process

Everything developed for our immersive content starts with actionable, skill-based learning objectives. These follow the Bloom's Taxonomy model (Bloom 1956; University of Arkansas 2022) and emphasize the more advanced levels of learning: applying, analyzing, evaluating and creating. During the content planning phase, learning objectives are written for every EBCx topic, each tied to tangible student abilities and project deliverables. The identification of training partners and the recruitment of training participants occurs at this stage of the process.

From the learning objectives, several deliverables are developed: a course description used for promotion, pre- and post-assessment questions, the conventional training content, and the immersive training content. We refer to this as the content development phase. As a best practice, it is important that the assessment questions do not influence the training content. Ideally, different members of the team write test questions and others develop the training content. Referencing the same learning objective objectives for both the conventional and immersive training content ensures that the desired course outcomes are consistent across both teaching approaches.

At the beginning of the training phase, all participants in the study complete the same pre-assessment. Then students are randomly divided into two groups: a control group and a test group. The control group views recorded trainings primarily composed of presentation slides and other conventional materials. The test group completes a training module built around immersive content. Both training courses will require similar time commitments, cover the same learning objectives, and include learning validation questions and other teaching best practices.

Once the training is completed, students will then complete post-course assessments. This data is archived for evaluation and used to determine effectiveness of the two instructional approaches. After a six-month period, students complete another post assessment. The second evaluation is to determine how well the students retain the information taught. We believe this second post-test will validate our belief that immersive learning creates a longer-lasting impression on students. This part of our process is defined as the testing and data analysis phase.

The last step of the process is the reporting phase where study results will be documented, the final report will be published, and project lessons will be compiled. Project lessons are the basis for improving the training content, and can be used to modify learning objectives, course descriptive information, training content, and pre- and post-test questions.

Project Status

This project encountered a couple significant setbacks after our ACEEE abstract was accepted. The Environmental Security Technology Certification Program (ESTCP) funding for this project was delayed at the beginning of 2026 and Whole Building Design Guide, the platform we intended to use for content dissemination and testing, is actively updating its platform and informed us in May that they are unable to post our content until the fall of this year. These setbacks impacted the project schedule and extended the time required for the content development phase, our current focus. The training phase will take place in the Fall of 2026 with the testing and data analysis phase scheduled for early 2027. The final report will be prepared in the Spring and Summer of 2027. The complete process, including planning, content development, participant recruitment, conducting trainings, testing, and evaluating results, are illustrated in Figure 4. While we hoped to be further along with this effort, the new timeline will allow us to conduct the content development and testing with additional rigor.

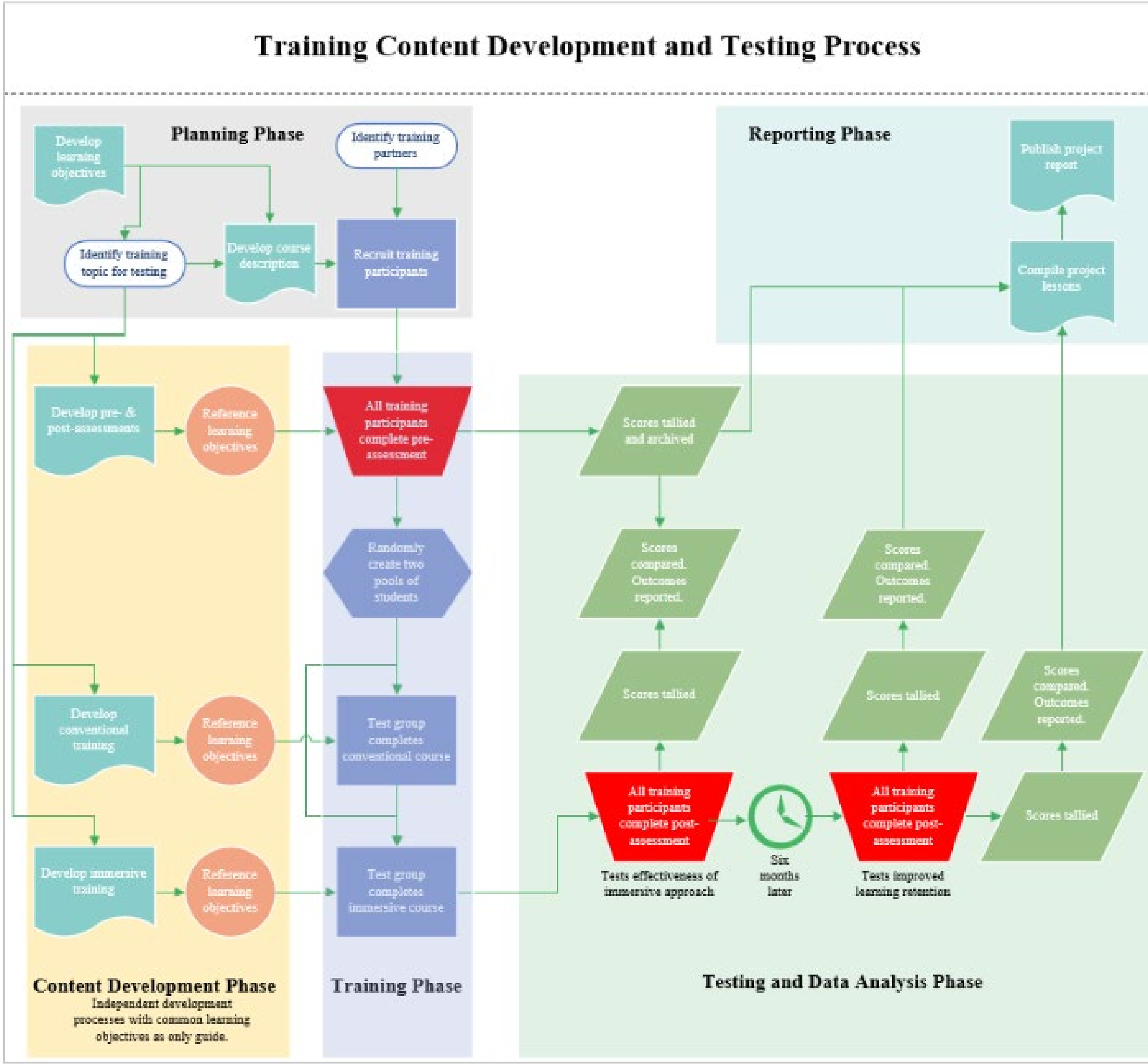

Figure 4: Flow Chart for Content Development Process

Performance Objectives

The project intent is to document three types of impact from the immersive environment study: improved knowledge gain, improved knowledge retention, and increased energy impact. Knowledge gain and retention will be tested using pre-and post-assessments of students able to access immersive and traditional content though public web sites like Whole Building Design Guide. We intend to also document testimonials and constructive feedback from our students as part of this effort. We believe this type of feedback will provide us with valuable information that we can leverage to improve the learner's experience. And we will collect lessons learned and students' observations from this effort including specific reflections on challenges we experienced developing this training content within a federal government environment. As stretch goals, we intend to measure energy impact at the project buildings used in the EBCx

Academy training series. This impact will be in the form of annual energy savings or improved Energy Use Intensity (EUI). All performance objectives are outlined in Table 1.

Table 1. Project performance objectives

Performance objective	Data requirements	Metric	Success criteria
Improved knowledge gain	Pre- and post- testing data of students before and after exposure to immersive teaching modules.	A larger increase in scores from pre to post for students using immersive models.	10% improvement over students exposed to conventional training techniques.
Improved knowledge retention	Quiz scores collected once after exposure to immersive teaching modules and again six months later.	A smaller drop in test scores for students exposed to immersive models.	5% improvement over students exposed to conventional training techniques.
Student surveys and testimonials	Feedback from training participants on effectiveness of immersive environment models.	As part of post-class surveys, we intend to ask students about their preference for immersive environment instruction versus conventional training techniques.	Students prefer immersive learning by a 20% margin. While anecdotal and subjective, we also think feedback from students will help us optimize this instructional approach.
Anecdotal evidence	Observations about challenges, special cases and remarkable successes.	Narratives from developer and user experiences (not a quantitative metric)	Range of user experiences that inform direction of initiative.
Stretch goals			
Increased energy savings	Projected and actual energy savings data from EBCx Academy project facilities.	Higher reported energy savings (normalized to kBTU) from students exposed to immersive models.	10% improvement over students exposed to conventional training techniques.
Reduced facility EUIs	Reduced EUIs (kBTU/sqft-yr) from EBCx Academy project facilities. Will need a year's worth of whole-building energy use from beginning and end of training series from MDMS or other sources.	Larger reduction in EUIs (kBTU/sqft-yr) compared to past training years when immersive environments were not leveraged.	5% improvement over students exposed to conventional training techniques.

We are actively exploring the best methods available to test and track the growth of student ability and the impact of education on achievable energy savings. Our previous experiences training building commissioning providers has shown that energy savings can be tied to education (Stroupe 2012). Potential savings will likely be comparable or more robust than energy savings achieved from behavior programs, since education of energy managers should impact the energy use of the facilities they oversee (Research into Action 2018). Behavior programs focused on the actions of building occupants and operators typically achieve energy reductions around 5% (Sussman and Chikumb 2016).

Training Content Development Examples

This section illustrates how our content development process works by exploring several examples. Each begins with the authoring of learning objectives that describe what students will be able to do after completing a specific portion of a course. Once learning objectives are in place, these are referenced to write assessment questions and develop training content.

Immersive Learning Examples

1. Education Building Hydronic System

Training unit learning objective: Field-identify critical HVAC system components.

For this training activity students are asked to navigate around a 3D model and identify HVAC components based on physical appearance and context clues. Once the desired component is selected, pop-up windows with information describing the functionality of the component appear. These windows can be linked to performance charts, videos that demonstrate equipment operation, or other useful information. Figure 5 shows five pop-up windows linked from one location in an immersive model.

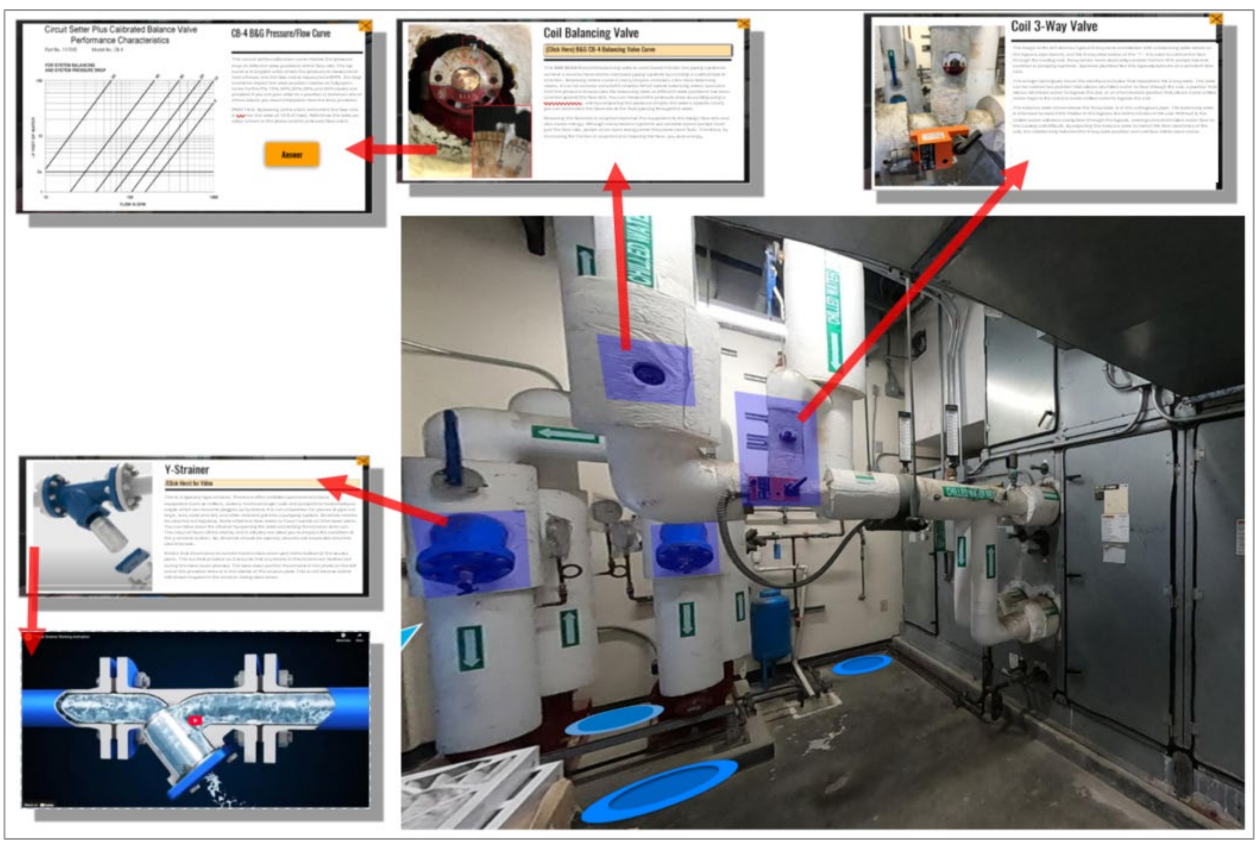

Figure 5. Windows describing HVAC components open from 3D model.

2. Bureaucratic Affairs Building Systems

Training unit learning objective: Recognize issues from field walkthrough.

Some of our 3D-immersive models are developed from SketchUp renderings rather than actual facilities. Though the models require more development time, they allow us to develop learning experiences around specific system configurations and issues. These models accommodate the same navigation features of the 3Dvista environment and allow for imbedded instructions, floor plans, and supplemental resources.

Referencing the identification of one energy efficiency measure from a scoping activity illustrates how virtual mechanical rooms are used as teaching tools. Students can click on the triple duty valve shown in Figure 6 and are asked if it represents an opportunity. As part of the investigation students must acknowledge that the valve is only 40% open. Ideally, they will have already found the pump's variable frequency drive (VFD) and recognize that throttled valves on variable speed pumps are creating unnecessary pressure drop and power draw.

This same measure can be utilized in subsequent training modules where students will determine motor efficiency, pump run time, plot performance data on pump curves and calculate energy savings.

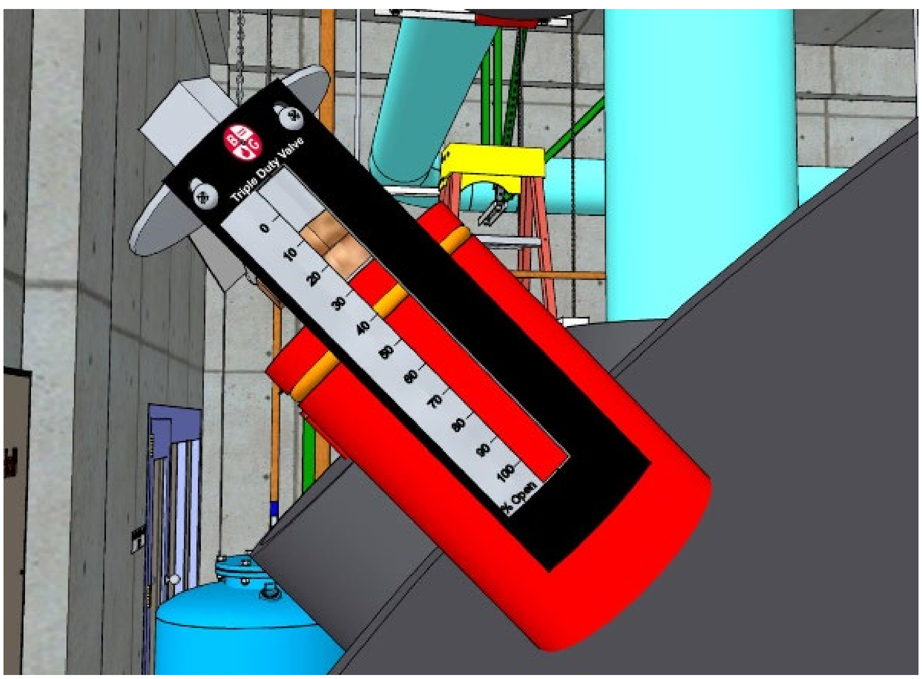

Figure 6. Imaged of throttled valve on pump.

3. Issue Discovery and Validation at Lab Building AHU System

Training unit learning objective: Recognize performance issues from functional testing.

This learning activity is based on an actual facility, and the learning activity is based on a real issue found at this facility. Students collect data from the model and address a series of questions to validate a specific fault. The activity leads to the collection of data which must then be deciphered.

The learner experience requires that students navigate to the mixed air chamber for an air handling unit. Here they can see several aspects of the configuration: Outside air coming in at the far end of the space, return air coming up from below and relief air exiting out the top. By clicking on the relief fans, a video opens that shows the near fan circulating clockwise and the far fan circulating counterclockwise as shown in Figure 7.

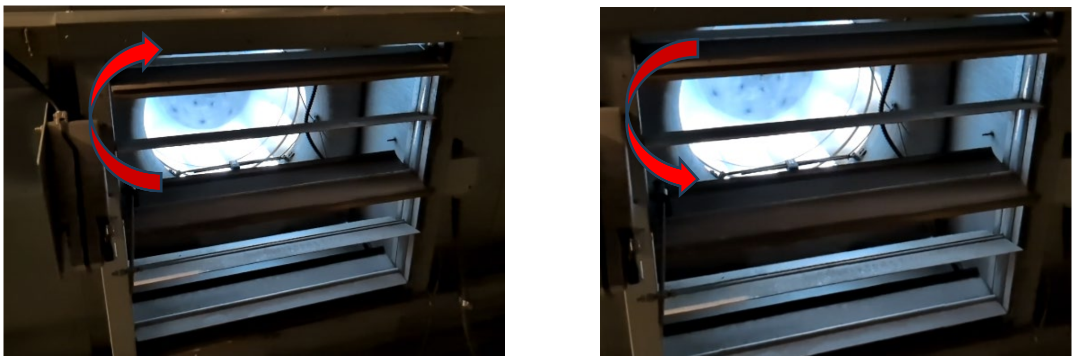

Figure 7. Relief fan on left rotates clockwise. Relief fan right rotates counterclockwise.

The variable frequency drive (VFD) speed and airflow for each fan are provided at wall mounted digital readouts. The near fan with a 60hz reading is providing about double the air flow of the far fan with a 12 hertz reading. Students are then asked what this indicates from these options:

a. The near fan operating at full speed is overwhelming the far fan operating at low speed.
b. The far fan motor is broken, allowing the fan to spin backwards.
c. With very different VFD speeds, one of the flow stations must be out of calibration.
d. We can't understand relief fan operation without building static pressure data.
e. This appears to be normal operation with the near fan ramping up first to full speed.

The correct answer is B: the motor on the far fan is broken. Students are then asked what they want to do next from the following list of options. For each option selected, the responses provided by the training interface are provided in italics:

a. Close the dampers on the far relief fan. *This is a good idea and will limit infiltration through broken relief fan path. Another option here is also a good idea.*
b. Check the calibration of the air flow stations. *The air flow stations may need to be calibrated but with the broken fan, the readings are plausible. Checking calibration is not a priority. Another option here is a good idea.*
c. Put in a work order to get the far fan motor fixed. *This is a good idea, but it should occur after other actions are taken.*

d. Measure temperature across filters to see if outside air is coming in through relief path. *This is an excellent idea and would allow one to see the magnitude of the impact of the broken fan. Next, let's decipher the collected data.*
e. Nothing. If outside air enters through relief path, building is receiving more fresh air. *This is not the best approach, and cold outside air could even freeze the cooling coil.*

When answer option D is selected the table shown below (Table 2) opens.

Table 2. Data from mixed air chamber traverse

MA temperature	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9
Row 1	69.5	70.6	70.9	68.3	67.7	67.3	68.5	68.9	69.2
Row 2	71	71.7	71.5	66.7	66.5	65.9	69.3	69.3	69.4
Row 3	70.7	71.6	71.5	66.8	66	65.8	69.6	69.4	69.6
Row 4	71.2	71.2	71.1	66.6	66.2	65.9	69.5	69.2	69.4
Row 5	71.7	71.5	70.9	67.1	66.8	66.9	69.7	69.6	69.8

Columns 1-3 are where outside air (OSA) enters after a preheat coil. Columns 4-6 are below the far relief fan, and columns 7-9 are below the near relief fan. Data was collected on a day with 45°F OSA, the OSA is heated to 115°F, return air is around 70°F, and supply air is at 53°F.

Students are then asked what the chart indicates from the following options. With each option, the responses from the training interface are provided in italics:

a. The preheat should be limited if supply air is controlled to 53°F. *This is true but preheat could be necessary on even colder days so that freezing air does not reach the cooling coil. Keep going, there are other correct answer options.*
b. The preheat is not effective if the average MA temperature is 69°F. *Because outside air is heated to 115°F, the preheat is effective. The lower temperature for mixed air (MA) is because the warm OSA has mixed with return air by the time it reaches the filters.*
c. The minimal temperature variation is an indication of good mixing. *The heat map shows clear temperature bands where preheated outside air, untempered outside air and mostly return air enter this chamber. These distinctions would not be this clear if air mixing is effective.*
d. The clear bands of warm, cold and intermediate temperatures are unrealistic. *Sorry, this is real data.*
e. Low temperatures in columns 4, 5 & 6 indicate outside air is entering through broken relief fan. *The low temperatures (lower than RA and preheated OSA) in the middle section confirm that OSA is entering through the broken relief fan, causing it to spin backwards.*

This activity concludes with a summary that describes the implications of OSA entering at this point in the system and next steps that should be taken to resolve the issue. The lesson learning objective, that performing a test and taking measurements to validate an issue, is emphasized. From here the students continue to explore the model to discover other performance challenges.

4. Developing a System Diagram from a Drawing

Training unit learning objectives:

- Develop system diagrams from mechanical design drawings, control graphics, and other system representations.
- Untangle system such that a minimum number of lines cross.

While still focused on the skill development of our students, some of our training activities do not require a direct connection to a 3D model. For this example, students are given a piping drawing from a mechanical system design and asked to convert it to a system diagram following guidance we provide. The piping drawing is shown in Figure 8.

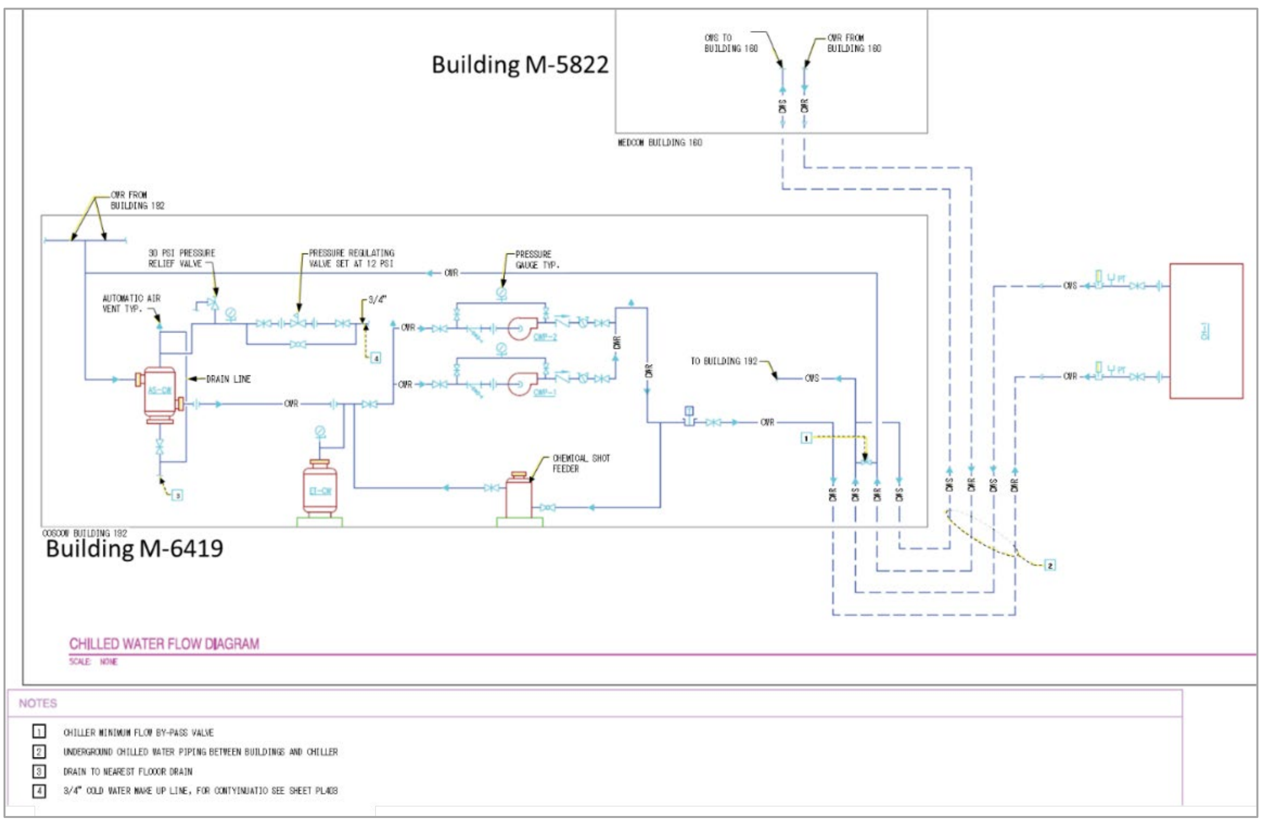

Figure 8. Piping diagram of chilled water loop

The exercise includes the following steps:

- Step 1. Identify the system type
- Step 2: Identify the major equipment
- Step 3: Locate the (main) tees
- Step 4: Identify additional critical component
- Step 5: Color code the lines
- Step 6: Locate the equipment anchors

- Step 7: Build the system diagram by connecting the components

Identifying the system type and listing the major equipment are critical first steps in this process; these components will serve as anchors in our eventual system diagram. If the media looped around a system in a simple circle, these diagrams would be much easier to construct. But most systems include subloops and alternative paths for the media as operating modes change. The subloops require 3-way intersections or "Ts" in the physical configuration and therefore the system diagram. Identifying the Ts in the piping drawing that will in turn be represented as Ts in the system diagram is the next step in this exercise. Students are asked to click on the "critical" Ts in the piping drawing. Critical Ts are required for system operation. The other Ts connect to support equipment and are not included in an initial system diagram. If they select correctly, a numbered box appears at the T. For the non-critical Ts an explanation is provided describing why the T is not essential to the initial system diagram. For this exercise there are 4 critical Ts and 22 non-essential Ts. See Figure 9 for the notes provided for each T.

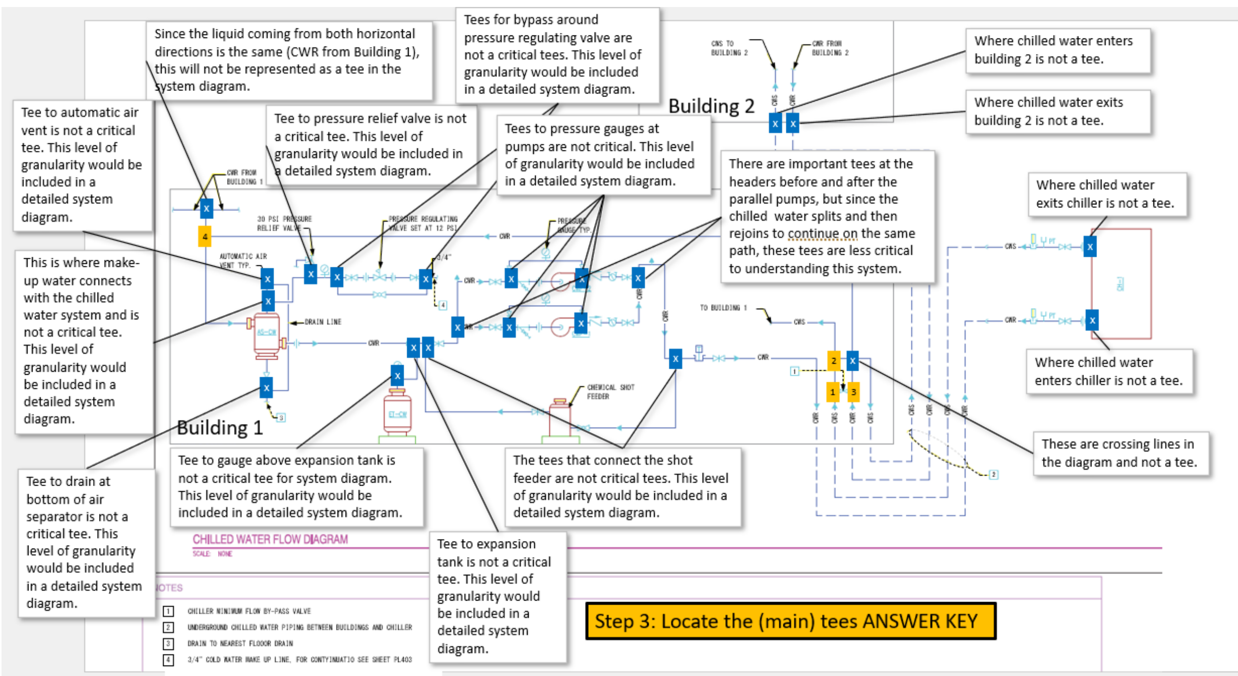

Figure 9. Identification of Ts in piping drawing.

Step 4 is to identify the balance valve between T-1 and T-3. Next the students are asked to identify all the connecting pipes in the diagram between the major components. There are 9:

1. A line connecting T1 to T2
2. A line connecting T1 to T3 that goes through minimum flow by-pass valve
3. A line connecting T1 to CH-1
4. A line connecting T2 to the loads at building 1
5. A line connecting T2 to the loads at building 2
6. A line connecting T3 to T4
7. A line connecting T3 to the loads at building 2

8. A line connecting T4 to the loads at building 1
9. A line connecting T4 to CH-1 that goes through the parallel pumps

These lines become color coded in the original piping drawing shown in Figure 9. Next the students locate the 8 major components by dropping the symbol for each on a blank page: the four Ts, the chiller, the parallel pumps, loads at building 1 and loads at building 2. The final step is to connect the components with the same, colored lines shown in the piping drawing to complete the system diagram which is shown on the right in Figure 10.

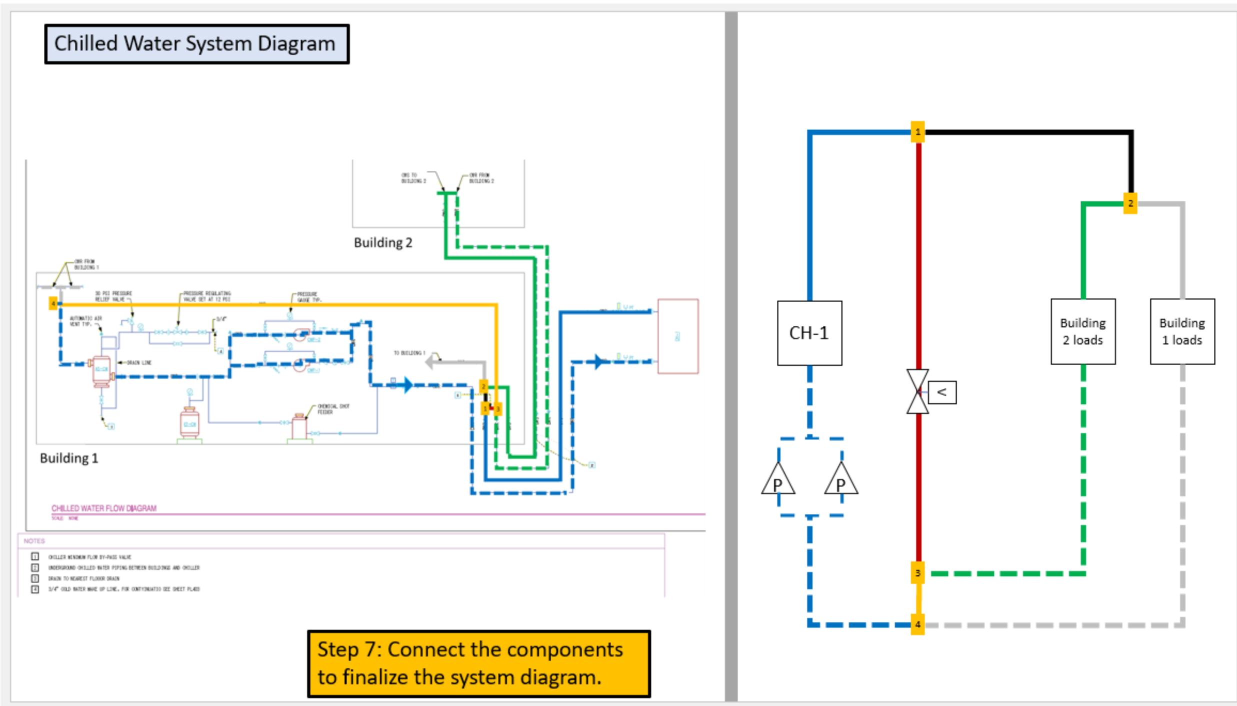

Figure 10. Corresponding colored lines to lines in final diagram.

Because we often develop system diagrams from drawings before field verification, teaching students to convert a design drawing to a system diagram is an important skill. An intended future training unit will allow students to field verify a diagram developed from a drawing using a navigable, 3D model. This training activity also reinforces the untangled, “ladder on its side” configuration we encourage throughout our system diagram instruction.

Learner Feedback and Development Team Observations

This research project is ongoing. As such, we have only collected learner feedback in support of the training phase (see Figure 4). Below, the authors present feedback from students and observations from the development team to date.

<u>Comments from EBCx Academy students on immersive instruction approach:</u>

- The 3D models of mechanical rooms and parts of buildings were very useful.
- I really enjoyed when we were able to walk through the model and identify HVAC issues.
- I really enjoyed the virtual walk-through environments.

- The immersive models provide opportunities for the entire class to look at a specific issue and provide different opinions.
- The models have been somewhat difficult to reach with my government computer.
- I love the variety of instructional approaches (simulations, virtual walkthroughs, interactive apps). It helps to keep refreshing points learned in a fun and engaging way.

Comments from development team on project challenges:

- Experienced challenges getting the models posted in the Army's secure environment.
- Experienced delays when the USACE team was short of software engineers.
- Experienced significant delays getting content posted on Whole Building Design Guide.
- Challenged to create conventional content for testing purposes when team is invested in immersive approach.
- Initial development of some exercises in PowerApps and TEAMS for Army students had to be converted to other platforms for our general public students.
- Project delays have given us time to develop a much clearer perspective on how we want to promote, conduct and evaluate the immersive training curriculum.

Conclusion

The immersive training program detailed in this study shows considerable promise for broader deployment at federal agencies and beyond as a modern approach to technical education. Feedback to date indicates that students not only prefer the immersive environment for instruction but also feel this training approach is ideal for grasping complex Existing Building Commissioning (EBCx) concepts. Concurrently, the developers of the curriculum appreciate that these immersive environments are infinitely adaptable and support global access to the content for a widely distributed workforce. While it is too early to determine if energy savings can be reliably achieved through this training approach, learner feedback strongly suggests that immersive training produces better student engagement and knowledge retention than traditional webinar instruction. This improved outcome suggests that learners will be more effective at performing the EBCx activities that often produce significant energy savings, thus presenting a compelling case for the continued development and expansion of this instructional method.

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Used for: final editing process
Extent: light editing / converting images to text / checked overall tone.
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