Issue in Focus:

3D Virtual Training in the Industrial Environment

Combining Learning Science and VR Technology to Add Value and Reduce Risk

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Introducing the Issue

Training employees in industrial environments is important to running a sound business. Effective training reduces risk, decreases liability, and satisfies compliance demands. Perhaps more importantly it improves efficiency, speeds up startup and deployment times, and increases productivity. Few would argue with the value of good training.

Unfortunately, some industrial settings make it challenging and costly to train personnel on real equipment or in the actual environment. Facilities like oilrigs often lie in remote locations where transporting instructors and trainees is expensive. Other settings may be unsuitable for training due to the danger placed on untrained workers. Learning skills such as cleaning up hazardous waste or combatting a fire in a hazardous environment like a nuclear facility can also be extremely difficult. In addition to being extremely dangerous for the novice trainee to explore for the first time, some environments are just not conducive to training. For example, emergency response exercises in a subsurface mine would be hard for instructors to observe and provide feedback because of the dark, cramped environment.

Some industrial settings make it challenging and costly to train personnel on the real equipment or in the actual environment.

Even if safety isn't an issue, training in some industrial environments may carry opportunity costs that negatively impact profitability. Taking equipment offline for training purposes leads to lost productivity. Temporarily scheduling a forklift for training might be acceptable, but there would be major cost implications to shutting down capital equipment producing "24/7." In other cases, it might not be worth risking expensive assets in the hands of trainees, where a single mistake could damage expensive or delicate equipment. In some scenarios, taking equipment out of service for training purposes is simply impractical from a scheduling perspective. For example, training new crewmembers on a vessel that requires a quick turnaround at the dock may not allow adequate time for effective training. There are also situations where the equipment or assets are not yet physically available, making it impossible to train operators until construction is complete.

Simulation Offers a Solution for Some

Training using simulation offers a solution to some of these training challenges. Simulation is the marriage of hardware devices, user interfaces, and pre-defined training scenarios. It provides the ability for employees and operators to work in a controlled environment where they are safe to practice a variety of situations under different conditions. Simulated activities are also more readily observed by instructors for evaluation and reinforcement. Physical simulators allow trainees to extensively practice a series of skills before they are introduced to the real environment. This is particularly helpful in scenarios described earlier where equipment can be expensive or remote and the dangers are real. This is why the air transportation industry, for example, has embraced flight simulators to train pilots for conditions such as engine fires or landing gear problems. It would be impossible and extremely dangerous to practice and perfect these situations in the real world.

Physical simulators allow trainees to extensively practice a series of skills before they are introduced to the real environment.

Many industrial settings, including air transportation, use physical simulators. Physical simulators attempt to mimic the actual equipment environment with a combination of custom hardware and software. Physical simulators, however, bring their own challenges. First, they are extremely expensive. A simulator can cost anywhere between 25% and 100% of the actual equipment cost for the hardware alone. This does not include custom programming, training content, or teaching instructors how to effectively use the devices. Due to the high costs, there might not be enough capacity available on physical simulators for everyone to use. This leads to the need for advanced scheduling and restricted usage by trainees, or a reduction of the training curriculum to a few, very specific situations. In addition, physical simulators are often large and difficult or impossible to transport, requiring additional costs for the trainee to travel to the equipment location.

Many skills can be trained using more cost-effective, readily available computer equipment and gaming controls, using computer-generated, 3D simulated environments and scenarios.

Physical simulators have their place. They are critical to train certain types of specific skills, typically those involving fine motor skills like using robotic surgical tools or operating specialized controls like those on a spacecraft. On the other hand, most skills requiring practice and evaluation don't demand such specialized and expensive equipment. Many skills can be trained using more cost-effective, readily available computer equipment and gaming controls, using computer-generated, 3D simulated environments and scenarios. Otherwise known as "3D Virtual Training," this has the potential to offer many of the same benefits of physical simulators without the high equipment costs. Using 3D Virtual Training opens new learning opportunities not available in traditional training environments, such as guided learning, the ability to replay the trainee's actions to identify and correct errors, integrated testing, and location independence.

3D Virtual Training Accessibility Expanding in Industry

The promise of 3D Virtual Training has been known for some time. Academics and scientists have acknowledged the benefits of using virtual environments to meet training needs and overcome the limitations of physical simulators. Despite the excitement of new technology, training with virtual simulators initially faced a number of obstacles. Developing a virtual training software environment requires a large investment since they demand dedicated programming interfaces, specialized developers with gaming experience, and highly skilled resources to build an interactive 3D model. These become very expensive, aren't scalable or easily reproducible from scenario to scenario, and therefore don't solve the overall cost issue associated with physical simulators.

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Today, thanks to evolution of graphics technologies, gaming platforms, and wide-spread use of 3D CAD systems, the promise of 3D Virtual Training is now practical in a larger variety of industrial settings. Virtual reality is being supplied on a range of platforms that are much more accessible to industry. The barriers to developing and deploying virtual training environments have dropped dramatically. Companies are developing immersive, interactive training environments on platforms ranging from low-priced, commodity laptops to physically immersive infrastructure using highly advanced technology. Industry is adopting these technologies to cost effectively replace training in challenging physical environments and leaving the use of expensive, dedicated physical simulators to only those scenarios that demand it.

Know what Virtual Reality Is (and Isn't)

Before we discuss the applicability of using virtual reality technologies for 3D Virtual Training in the industrial environment, let's provide some definitions. First, let's define virtual reality. For the purposes of this discussion:

- Virtual reality is an ***immersive, interactive, computer-generated simulation intended to mimic real life or imaginary experiences***.
- As Wikipedia explains, "*Most current virtual reality environments are primarily visual experiences, displayed either on a computer screen or through special stereoscopic displays, but some simulations include additional sensory information, such as sound through speakers or headphones. Some advanced, haptic systems now include tactile information, generally known as force feedback, in medical and gaming applications*."

It's important to understand what virtual reality *isn't*. One key point to take away from the Wikipedia definition is that virtual reality does not necessarily require specialized goggles, helmets, data gloves, motion detection, or other advanced hardware. Virtual reality doesn't have to involve a lot of expensive equipment. In fact, many virtual reality environments are simply displayed on a laptop computer screen. In other words, there are different a variety of approaches to virtual reality with increasing levels of visual immersion and sensory user interfaces. Industrial companies can now choose the level of virtual reality that's right for their training needs, capabilities, and budgets.

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Explore the Science of Virtual Reality for Learning[1]

With that understanding about virtual reality, let's talk how it can be applied to improve human learning. The science connecting virtual reality with effective learning has been known for some time. There is a tremendous body of research in this field, which we will summarize as concisely as possible to provide some helpful background information for those who are interested. In particular, the science identifies a number of key points relevant to the use of virtual reality for training in industrial environments.

- **People learn better by doing** – It's common wisdom – and research proves – that people learn better when they are actively engaged in learning. "Learning by doing," instead of just reading or listening to presented material, uses a part of the brain that assimilates information much more rapidly. People learn this way by building mental understanding of the material, testing it by interacting with their model through trial and error, and then enhancing it by making and correcting mistakes while solving problems.
- **Simulation stimulates "learn by doing" mechanisms** – Performing tasks in a virtual environment activates the same processes in the brain as executing the tasks in the real world. When a trainee experiences the "cause and effect" of an action in a virtual environment, this produces a "double-loop learning mechanism" where the trainee can form, test, and revise their interpretation of the experience. This is a key element involved in the transition from learning to remembering and understanding specific procedures.
- **Performing physical tasks virtually is a very effective way to learn** - Visualizing performing a task or watching another person do it stimulates something in the brain called "mirror neurons." In a 3D Virtual Training environment, for example, the simple act of clicking a button on a joystick and then watching a virtual avatar turn a valve will stimulate the same motor neurons used to actually turn the valve, causing the trainee to gain "muscle memory" in the actual performance of the task.

- **Knowledge learned in the virtual environment can be successfully transferred to the real world** – Studies show that learning in 3D virtual environments is comparable to real-world experience in learning. Because 3D Virtual Training is stimulating the brain with the same double-loop learning and mirror neurons that are experienced in the real world, the virtual training can be a powerful replacement to physical training.

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The body of research also shows that virtual training is feasible with today's technology. The studies did find some specific requirements that make virtual learning more useful. Effective learning through virtual reality requires:

- The ability for the participant to <u>move freely</u> in the virtual environment
- The capability for the individual to <u>control their view and position</u>
- Realistic behavior and <u>interaction</u> with objects
- <u>Realistic imaging</u>, such as perspective, shading, shadows, and texture
- The ability to <u>perform tasks</u> that correspond to real-world activities
- The presence of an <u>instructional framework</u> to guide activities and track trainee actions

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In essence virtual reality offers a way to "learn by doing" without having access to the physical environment or specialized and expensive simulation hardware. Numerous studies prove the effectiveness of this approach. For example, virtual reality has proven highly successful to help rehabilitate people whose bodies aren't capable of completing a task but can effectively learn by conducting the activity in a simulated, 3D environment. A study in a hospital with immobile patients showed they could learn to navigate the halls of the facility by learning in a computer-based, simulated environment. These patients were able to demonstrate their learning by successfully navigating around the actual hospital as their mobility increased, demonstrating that the 3D Virtual Training produced a powerful memory and learning of the environment that could be applied in the real world.

Past studies also acknowledge significant barriers to using physical simulators on a wide scale in all but the most critical learning environments such as airplanes or spacecraft. On the other hand, the studies showed that using 3D Virtual Training in a purely visual mode using a desktop computer system is sufficient to gain a coherent mental representation, producing an effective learning environment. The scientific research concludes that today's technology can effectively create an immersive environment using basic, readily available equipment.

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Leverage (Military and) Gaming Industry Investments

3D Virtual Training is now practical for industrial environments, with leading companies taking advantage of the technology today. So, how did this come about? In the past, few organizations could invest in the technology required to power real-time, virtual simulation environments. The infrastructure required to provide a realistic environment, effective interaction with participants, and lifelike interactive models requires a significant investment in technologies such as physics engines and lifelike rendering engines. It also demanded very specific or highly customized programming resources. This required too much investment for an industrial company to consider adopting 3D Virtual Training themselves.

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The investment required to develop the technologies to support 3D Virtual Training was only feasible to serve highly specialized, well-funded, one-of-a-kind initiatives or to produce scenarios that would appeal to a mass market. Thanks to the gaming industry, there has been a successful crossover of this technology to the mass market. The commercialization of technology requires the convergence of several elements: available and affordable hardware, software capable of producing effective user experiences, and a large enough market for companies to justify their investments and ultimately make a profit. The gaming industry created a competitive market for dedicated gaming devices, computer equipment, and consoles for gaming. Gaming successfully developed into a mass market of consumers purchasing and enjoying video games. The gaming culture and gaming technologies were then able to trickle back over into other industries and usages, such as the use in physical simulators and now 3D Virtual Training.

The early investment in gaming technology for 3D Virtual Training came from the defense industry, which grew up in parallel with the gaming industry. The initial development of first person and virtual gaming experiences in the military then resulted in the availability of off-the-shelf tools for realistic, real-time rendering and interaction required for a larger and gaming industry. In fact, gaming technologies have now progressed to the level that most military organizations are now switching to these commercially available technologies instead of continuing to develop their own.

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Today's gaming technologies provide the tools needed to make 3D Virtual Training accessible to leading industrial companies. A robust gaming engine offers the following modules to provide the capabilities necessary to create 3D Virtual Training for industrial environments without the need to learn complicated graphics programming interfaces or build complex mathematical simulation models:

- **Gaming engine** – Supports the development of logic and objectives to enable guided learning starting with the ability to offer demonstration (3rd person), move to guided interaction (1st person), and graduate to more free exploration (1st person), and manages participants' attainment of objectives.
- **Rendering engine** –Serves up realistic graphics in real-time and 3D, enables viewing with realistic textures and shades, and offers views from different camera angles such as first person or a bird's eye view.
- **Physics engine** – Provides interaction between physical objects and enables real-world effects like gravity, friction, collisions, trajectory, and sound.

Companies can now develop an immersive, interactive environment with standard laptops.

These solutions are designed to meet the demand for realistic representations and interactions using commodity hardware. Companies can now develop an immersive, interactive environment with standard laptops. If they choose, they can enhance the environment by adding 3D displays and 3D glasses, head/hand tracking devices, and perhaps touch/force sensors (haptics). But virtual reality no longer requires a multi-million dollar, fully immersive environment. Of course, 360 wrap-around screens with helmets, eye movement tracking, and more can add additional value in specific training scenarios. But research shows that simple environments can be just as effective at much lower cost, and these simpler approaches are actually less likely to result in common side effects such as vertigo or nausea.

Utilize 3D Assets to Reduce Effort

With the gaming software infrastructure in place, developing virtual interactions becomes much easier. But realistic training using these virtual reality techniques still requires significant investment in developing lifelike, 3D models of the environment and equipment. Accurate distance and direction between objects is important to developing proper spatial awareness, but the time and cost associated with manual 3D modeling of real environment into a virtual world can be prohibitive. Fortunately, the barriers to digitizing physical environments have fallen due to the increased use of 3D computer aided design (CAD) tools and reality capture techniques such as 3D laser scanning. Now, companies don't need to pay 3D artists to recreate their environments from scratch because they can reuse their 3D CAD designs. This is similar to what Tech-Clarity's The Business of 3D Technical Communications paper recommends that industrial companies do in other areas of their business, for example saying to "*Leverage existing 3D assets (CAD models) to improve technical documentation efficiency*." As with improving the efficiency with technical communications, the same is true for developing 3D Virtual Training simulations, opening up the potential to reuse digital assets from 3D CAD and visualization tools.

Reusing 3D assets also allows companies to quickly access various equipment configurations and automatically apply realistic textures, shadows, equipment movement, and other attributes based on actual design information.

Reusing 3D CAD assets provides the realistic, lifelike representations required for effective learning. This reuse clearly saves time and money creating environments compared to developing them from scratch. It also prevents the need for 3D artists or developers to interrupt engineers with requests to make screenshots or to answer questions, since the engineer's original design knowledge built into the 3D models can be accessed and reused directly. Reusing 3D assets also allows companies to quickly access various equipment configurations and automatically apply realistic textures, shadows, equipment movement, and other attributes based on actual design information.

Tying all of the content together inside an integrated information system manages the relationships between the CAD parts, the training procedures and curriculum, what courses the trainees have taken, and the trainees' results.

Another big advantage of reusing engineering assets is that companies can associate their training environments to the underlying CAD objects so they can readily update training when equipment changes. In fact, tying all of the content together inside an integrated information system manages the relationships between the CAD parts, the training procedures and curriculum, what courses the trainees have taken, and the trainees' results. This enables full traceability in the case that any of these elements change. For example, the system could determine what procedures are impacted and identify what users might require notification or retraining if an underlying CAD structure changes.

This integrated approach allows training to stay up to date as the physical environment changes over time due to ongoing engineering and operational improvements.

Learn from Others

The good news is that using 3D Virtual Training in industrial environments is no longer uncharted territory. Industrial companies are taking advantage of the lessons learned from the early adopters in addition to leveraging the technical investment from the gaming (and defense) industry. The benefits of 3D Virtual Training are more feasible today and not just a matter of academic pondering. Many companies are taking advantage of the lower barriers to entry by using gaming technology, existing 3D assets, and commodity equipment. While this approach may not be appropriate for everyone or all training scenarios, leading industrial companies can now make use of it to gain an advantage over their competition.

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The Royal Australian, for example, Navy ran a 3D Virtual Training program for submariners known as LASTS (Location and Scenario Training System). The LASTS program was the subject of an academic analysis of the feasibility of using virtual reality for training. The research uncovered significant benefits comparing those that learned a "12 point safety round" procedure through 3D Virtual Training with those that learned using a more traditional approach. Those that participated in the 3D Virtual Training produced significantly better results than the traditional group. In particular, they:

- Demonstrated a greater knowledge of the equipment (submarine)
- Were better able to recognize items
- Were able to complete the inspection process with more confidence
- Performed the 12-step process in about half the time

A prominent energy company uses virtual simulations to orient people to their complex industrial settings. Part of the goal is to familiarize participants with the remote environment and practice identifying equipment prior to deployment. The scores from those participating in the virtual reality training went up 300% compared to those attending traditional classroom training, even before the environment was constructed. In addition, the virtual simulation participants reported higher comfort levels than those that didn't have the benefit of the virtual environment when asked how they would feel if they were immediately deployed to the remote location.

There are other examples as well, including some that have used more advanced techniques, such as University of South Wales with a fully immersive 3D training program to promote safety for miners. Others include training for RAID, the French SWAT team, and the German Army training on M3 Amphibious Vehicle. This last 3D Virtual Training environment is particularly interesting because it involves multiple participants in a synchronized virtual simulation.

Conclusion

Effective training helps industrial companies reduce risk and improve profitability. Scientific research shows the potential for these companies to take advantage of virtual reality technologies in training, improving their training delivery and optimizing the way their employees learn. 3D Virtual Training offers industrial companies an opportunity to offer their employees an improved training experience that provides better retention because trainees have the ability to repeat procedures more frequently and within a safe environment. 3D Virtual Training allows employees to start working their first time on real equipment with the equivalent of "on the job" experience, performing their tasks safely, efficiently, and correctly.

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Due to advancements in the gaming industry, industrial organizations can now cost-effectively leverage more accessible software and commodity hardware to provide the real-time, interactive environment needed for effective 3D Virtual Training. Further, by reusing existing 3D CAD assets in a virtual environment, industrial organizations can take advantage of the benefits of 3D Virtual Training with fewer resources and lower total cost. Companies can take advantage of this solution to get the value of hands-on, interactive training with lower cost and reduced risk, while eliminating the need to take valuable production equipment offline.

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The convergence of gaming technology and 3D CAD assets puts 3D Virtual Training environments within reach of those companies that couldn't access it before, opening up many new opportunities for top- and bottom-line benefits. Leading industrial companies can now take advantage of a more transportable, flexible, and cost effective option for training that leads to higher productivity, faster ramp up speed, reduced travel costs, and the ability to keep personnel and training procedures updated as facilities and equipment change.

Recommendations

Based on industry experience and research for this report, Tech-Clarity offers the following recommendations:

- Recognize the potential for 3D Virtual Training to overcome obstacles in your training program (equipment availability, cost, etc.)
- Don't reinvent the wheel, leverage the significant technical investment of the gaming industry by using standard, "off-the-shelf" gaming, physics, and rendering capabilities
- Get more value from existing 3D CAD assets by using them to develop realistic settings for 3D Virtual Training
- Focus on instructional intent and determine where 3D Virtual Training can reduce cost and provide advantages over physical simulators

References

[1] To learn more about the science of learning and 3D simulation, including a very helpful list of references, see Sub space: Enhancing the spatial awareness of trainee submariners using 3D simulation environments by Michael Garrett, Edith Cowan University. The paper is available in the National Library of Australia. We would like to acknowledge the fine work of Mr. Garrett in compiling a compendium of research on this subject.

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