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THE BENEFITS OF USING SIMULATION BASED TRAINING (SBT) TO IMPROVE SAFETY IN THE CLASSROOM AND WORK FORCE

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ABSTRACT

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Simulation Based Training (SBT) in education refers to such labeled activities as gaming, gamification, 3D environmental training, virtual reality, and/or augmented reality. In this day and age simulation training is common place and even expected by today's students. If a student can play virtual reality games using their phone, why wouldn't they expect to be able to learn this way for a course. We know from educational studies that students learn best by using the same methods or the same way they played as young children, and today's students grew up playing video games. This means in the field of education we need to start incorporating simulation as a teaching tool because this is what our students have grown up using. Career and Technology Education and other lab based courses face additional challenges when it comes to education students due to the 1) cost for equipment, lab, and/or teachers; 2) major safety concerns on the tools the students use or skills they may need to practice; and finally 3) to find ways to increase students' knowledge and problem solving skills.

Keywords: Simulation Based Training (SBT), Immersive Virtual Environment (IVE), Multiuser Virtual Safety Training System (MVSTS) Career Technical Education, Vocational Education, Lab Based, Training, Games, Gaming, Gamification, Virtual Reality, Augmented Reality, 3D environment, STEM, Manufacturing, Safety, Cost, Labs, Work Force

The Benefits of Using Simulation Based Training (SBT) to Improve Safety in the Classroom and Work Force

PROBLEM STATEMENT

According to the 2015 US Bureau of Labor Statistics in the US the industries with the highest reports of occupational injuries and illnesses are 1) Health and social care, 2) Manufacturing, 3) Retail trade, 4) Food services, and 5) Construction. For a comparison the 2016 UK Health and Safety Executive reports that it’s are 1) Health services, 2) Construction, 3) Agriculture, 4) Manufacturing, and 5) Gas, Electricity, water supply. So it makes sense that when a search is performed on safety and simulation training 13,806 articles are found in relation to the medical field versus only 5,590 found for construction or manufacturing. The study of simulation and the medical fields is being well covered by others. So the focus of this article is on finding a way to effectively increase safety training in the manufacturing and/or construction fields. Especially since the manufacturing and construction are the next top two industries found to have the greatest need to find ways to provide affective safety training to all of its employees.

Hashemi, Ahmed, and Khan has reportedly found that the number of industrial accidents caused by human error has been growing globally in recent years (2014). It has been calculated that human error causes between 60-80% of all reported industrial accident from across all nations for manufacturing and/or construction (Nezar and Manca, 2014). Even in nations who have industries well established like the US or the UK struggle with finding ways to safely and effectively train their workers. These industries are all hands on and as such rely heavily on the experiential learning process; this will be explained in detail later in this article. As a result, this has led these industries seeking out new ways to train their people. The training method that this article covers is simulation-based training (SBT) that combines an Immersive Virtual Environment (IVE), multiuser virtual safety training system (MVSTS), with its own built in automated assessment. For consistency this will simply be referred to as SBT for the rest of this article. Educators have been championing for the use of SBT since the 1990s (Nezar *et al*, 2014). The literature reviewed for this article all report that a quality SBT will be the most viable solution to improve safety and decreasing the high cost of accidents. This is because SBT training should improve (1) and make operations that need to be performed less hazardous and thus result in fewer accidents. Fewer accidents results in (2) no down time resulting in loss of production time. It also (3) reduces potential harm to people within the work zone due to chemicals or other dangerous materials being released due to an accident. Resulting in (4) better utilization of limited materials. Finally, and most importantly, it (5) reduces the number of casualties or deaths.

INTRODUCTION

It is not surprising that human error accounts for between 60-80% of all reported accidents in industry that lead to injuries of either the human operator or other fellow workers. This is attributed to the high cost of materials and/or facilities that are needed to provide proper traditional hands on training. Training that is needed to ensure that the skills workers must have, has been taught at the level required for safety and work efficiency. Thus improving quality of product or services and safety in the work environment. Unfortunately, the extensive training needed isn't always affordable for companies to do, especially the traditional hands on, experiential style. Due to this issue of expense, studies have been conducted by researchers such as Jacobson, Taylor, Richards, and Lai who found that gains in learning have been found in certain simulation activities or training (2013). For the purpose of this article, simulation is defined by de Jong and van Joolingen and it is “a program that contains a model of a system (natural or artificial) or a process” (1998). Computer simulation can be virtual, augmented, two, or three-dimensional traditional computer game play. However, the three-dimensional modeling is found to be the best training model used in secondary education courses (Smith, 2003). As such industry has started to follow the results gained from secondary education studies of the effectiveness of simulations to teach theory and application in what would be traditional lab based courses work. Resulting in SBT being adapted and used not only in schools but in industry.

Antonovsky, Pollock, and Straker found that 79% of accidents in the oil and gas, a manufacturing, industry where the result of human operator error (2014). A great example of human error that results in greater danger is Nazir and Manca, who discovered that the demands on human crane operators has shifted from physical to being more mental (2014). Research has started to prove to management that training is what will improve the operator’s knowledge and will result in fewer accidents or at least reduce the severity of the accidents. Additionally, the training must also recognize that operator is not the only person who should be held responsible for the accident. That instead the system and at all organizational levels need to be included in the training process to fully address the safety training needed for the operators and those who interact with the process being performed by the operator. Anyone involved in the process, be it as support or as a general worker in the area, needs to be trained on how his or her actions can affect the operation of the crane. Leading to studies on how SBT results can increase safety for everyone involved. Kluge, Nazar, and Manca paper has called for the creation and implementation of SBTs that result in improved performance for all of the operators and any other workers who interact with the crane operators under normal or abnormal work place conditions (2014). The SBT that a particular industry selects to use must meet the needs of their specific industry, in this case crane operators, and teach cognitive related task (Columbo, 2016). It must also teach the manual, often repetitive, physical tasks (Bullinger, Breining, and Braun, n.d.). Current training methods are often lacking in content, adequate number of training sessions, and/or has to rely only on mentor who does on the job training (OJT) to teach the operator how to safely perform their job (Salas, Tannenbaum, Kraiger, and Smith-Jentsch, 2012). Adding to this is Manca, Nazir, Lucernoini, and Columbo study found that what training that does exist, lacks an assessment component to measure the often-exhausting tasks that the operators are doing, the human interaction causes, and/or the organization systems issues involved (2012). Safety training must meet all of these needs to be successful, SBTs are a way that industries can provide training needed in a safe, affordable, and timely manner.

There are some industries who have been early adopters and who have had much success with SBT's. Aviation and the military have traditionally been the leaders or early adaptors of SBT's. In 1991 Moroney and Moroney designed the Microsoft Flight Simulator. The use of simulation or gaming for technical or workplace learning isn't new. Ahrens study found that the military has been following Kolb's experiential learning cycle for years to train soldiers for the strategic skills needed to win in dangerous situations (2015). Soldiers work through these ever evolving and increasing levels of "war games". The military use the simulation or games because the game provides high quality, low costs, and a realistic immersive learning environment where failure does not lead to injury or death. In 2001 the US Army developed an SBT that integrates existing game-engine technology to create their mission rehearsal exercise (MRE) virtual reality training environments. Both of these SBTs confront the trainee with different predefined dilemma's that the user is known to most likely face when working in the field. The trainee then is presented with the consequences of their decisions made in the virtual environment, making them better prepared to experience similar dilemmas in the real world (Li, Chan, and Skitmore 2012). Resulting for these early adopter industries have (1) less accidents, (2) increased the number of trainees who can be trained by using the SBT, (3) less harm to others, (4) saved on expensive fuel, equipment, armory, etc., and thankfully (5) reducing the number of casualties and death.

The success aviation and the military has had with using SBT have already resulted in many other industries who have also started to adopt this method of training by SBT. Some more examples of industries who have already successfully adapted SBT are DeLean and Berry photorealistic environment walk through of 2000. Cavazza, Charles, and Mead interactive storytelling of 2002. Refsland, Ojika, Defanti, Johnson, Leigh, Loeffler, Tu, and Heudin large scale real-time ecosystem simulation of 1998. Lepouras and Vassilakis virtual museums of 2005. Bouchard, Cote, and Richard phobia therapy 2006. e-Tourism developed by Berger, Dittenbach, Merkl, Bogdanovych, Simoff, and Sierra in 2006. Frey, Hartig, Ketzel, Zinkernagel, and Moosbrugger psychological experiment of 2007.

The construction industry has recently started to study and see if the SBT could be adapted to their needs. In 2012, Li *et al* performed a study using 30 crane-dismantling riggers. Group A had 10 with no experience or training. Group B and C had 10 each with who had experience and had just recently successfully and safely performed a crane-dismantling. Groups A and B trained in the SBT given different game training regimes and their performances were assessed later. All 30 then took a 20 multipole choice short post quiz. Scoring group averages were reported to be for A= 24.2, B = 26.1, and C = 24.3. This shows no statistical difference between any of the groups, with B being just slightly higher suggesting that some prior knowledge combined with the training has slightly higher results. However, those with experience and those with only SBT score was only 0.1 difference. This pattern was repeated when the researchers checked for correlation in scores for location (A= 8.1; B= 8.8; C = 8.0) and duty (A= 8.3; B= 8.6; C = 8.1). The only slightly lower result was in sequence with a high of 8.2 with the experienced group C versus 7.8 the group with only simulation training group A, and again group B has the highest score of 8.7. Resulting in the theory that SBT can be created, used, and result in improved success rates for meeting the needs of other specific production-based industries.

Current training methods or experiential training that are only provided by only by hands on doing has been the only option for most industries up until recently. The problem with traditional experiential experience only training is, that during the training there is a greater chance for (1) accidents, (2) only one or two trainees can be trained at a time, (3) the potential harm to others is greater if the trainee makes a mistake, (4) and it is expensive when it comes to the use of equipment, materials, etc. Eventually it does lead to (5) a reduction in the number of casualties and death, but at the expense of time and money. Most companies are limited on the funds available to be spent on training, resulting all too often in not enough training being offered due to time, mentors, equipment, etc.. availability. This has resulted in process-based industries requesting training that is repeatable and that adapts to the skills level or needs of the trainer. Additionally, companies have started to ask that the training assessment be automated to ensure that the results are neutral and based solely upon the trainee’s performance. Doing this will remove the subjectivity that is involved when human judgement is used to measure performance (Manca *et al*, 2014).

EXPERIENTIAL LEARNING

A discussion and explanation of the experiential learning model must be addressed first to explain how SBT can be utilized and is beneficial to the construction and manufacturing industries. Smith describes experiential learning as the sort of learning undertaken by those who are given a chance to acquire and apply knowledge, skills and feelings in an immediate and relevant setting (2001). Meaning that trainees receive more than just theory, time is spent actually applying and practicing the skills explained or required in the lesson. Experiential learning always focuses primarily on involving the student with a direct experiential encounter with the learning event rather than simply a thought process associated with the learning expectation (Borzak, 1981). This is better explained in figure 1 stating that students acquire feelings and knowledge in the learning environment. Trained workers must apply these to get the skills needed to be safe and successful.

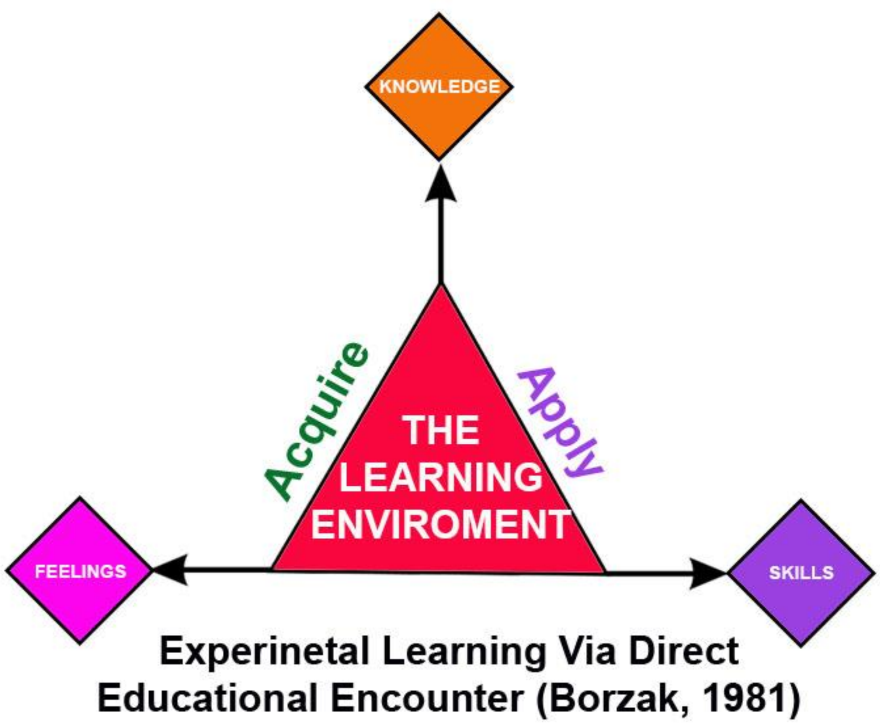

Figure 1

There are many various models that explain authentic experiential learning. The method most commonly referenced is Kolb's four-modality model learning cycle (1984). Successful training programs do not just focus solely on the hands-on phase of experiential learning in Kolb's learning cycle. Instead, the trainer choses which of the four modes to use to introduce students to the knowledge and skills being taught, based upon the needs of that student. Then the student continues on through all four stages of the cycle just as Kolb and Fry have outlined (1975). Simulation is an ideal method of instructional delivery as it involves and cycles through all four of these stages. Compare this to Smeds, Jaatinen, Hirvensalo, and Kilpio research on how experiential learning and simulation results in a continuously evolving model, that starts at the stage of which the participant currently is and then it moves them on to the next stage (2006). This process does not end until the student reaches the minimum level of competency of knowledge and skills required to be able to contribute positively to the task at hand. It continues to evolve in its complexity and learner outcomes. Resulting in the experiential learning process is more tailored to each persons learning objectives and level of complexity required.

In Kolb's experiential learning model, the learner or trainee can start at any of the four domains. Usually the starting place is in the "Feeling" stage where the trainee us told, taught, or have seen first-hand what happens when a procedure isn't done correctly. This then leads to the "Watching" stage where the trainee must try to figure out why something happened. Was it human or some other kind of error? This is often referred to as the why state and can arguably be the most important stage because the trainee reflects and internalizes what happened and their part in it. Stage three of "Thinking" is when the trainee formulates exactly what the actions that are going to be taken or done, and express what they think will happen instead. The stage where a trainee should spend the majority of their time is four or “doing”. Trainees have to actually put into practice what has been hypothesized or think will happen, which often takes much longer than feeling, watching, or thinking. If the trainee hypothesis is right and the skills has actually learned then it is time to move onto another or more complicated one. If it is wrong then the trainee goes back feeling and start the process again. Figure 2

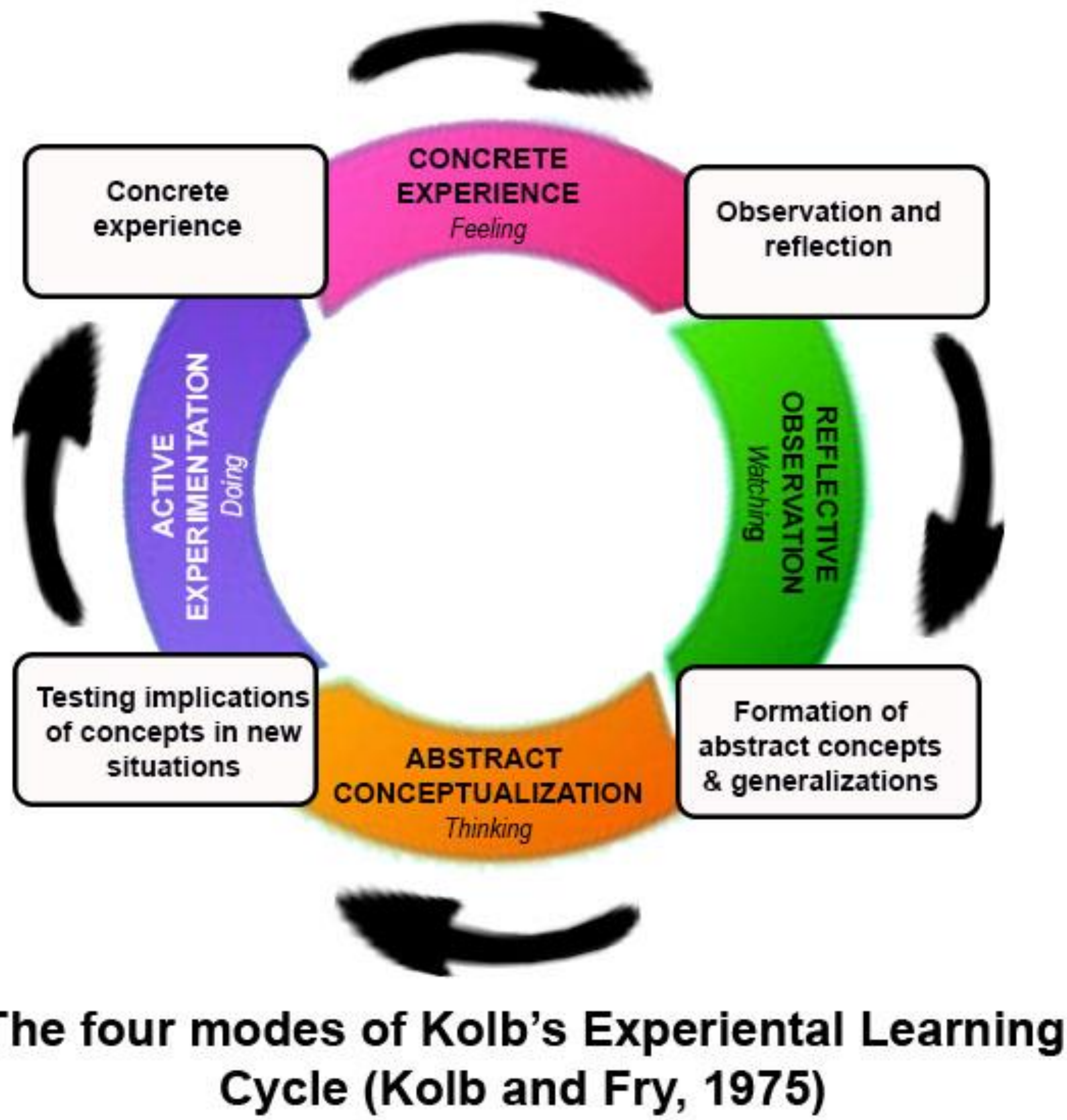

Figure 2

Smed’s *et al* experiential learning model can also start at any of the stages but typically, it starts in the “feedback” stages. Where the trainee observes past lessons or reflect on previous experiences and how those apply to the current issue. Then the trainee begins to define cause and affects and/or identify similarities. Once those have done, then it is time to move onto coming up with hypothesis of if “C’ is done instead of “Z” what will then happen? Formulating ideas or plans that will improve the situation or solve the problem, as it is currently understood. Once the situation or problem defined then it is time to seek out research or people who have experience to find out what worked for them. If there are none available and content cannot be found, then the next step is to move straight into trial and error experimenting. Finally learning by experiential experience happens by the trainee actually doing the what was hypothesized and then review what happened. To find out was the results better or worse? Leading back into the learning from feedback based upon what happens in the experience stage. Ideally each time a trainee goes through the stages the score gets better or eventually so good that a new skill to learn or problem to solve is provided. See figure 3.

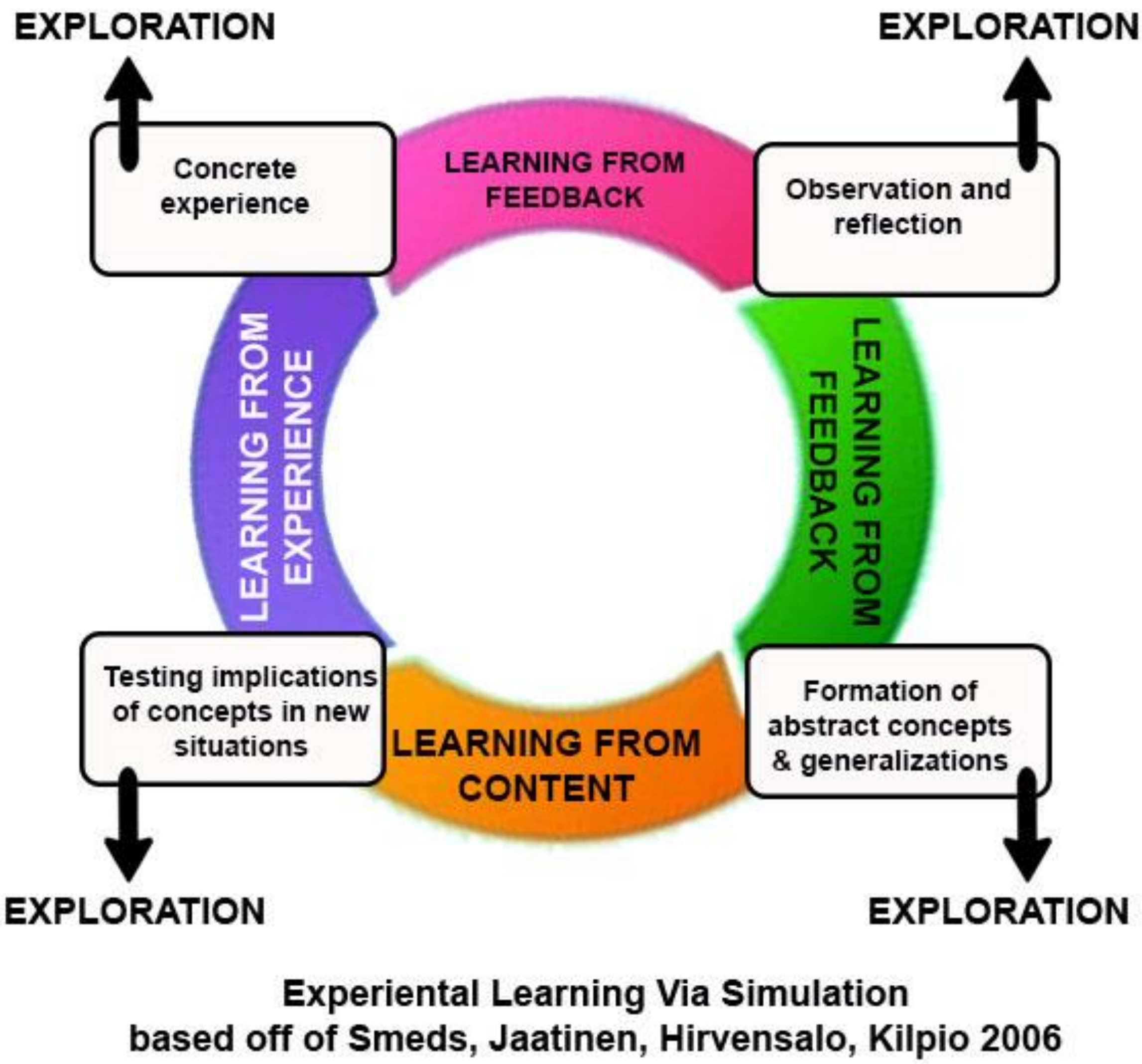

Figure 3

Adock's research has shown that game-based learning helps learners transform the ambiguity of the learning process using trial and error in a safe environment, thus allowing the users to gain and retain new knowledge (2008). Governmental agencies such as Germanys Federal Ministry of Education and Research have invested in simulation or gaming that focuses on work process competency needed for the "harbor of the future" (Retrieved from http://www.arkoh.de). This research focuses on the two work processes of 1) safely loading offshore wind energy components and then also 2) loading, moving, storing, and securing loads. Ahrens reports that Germany knows that their workers need basic knowledge in physics, mathematics, working with complex technologies that require them to work cooperatively, and constantly changes scenarios (2014). Without investing in and using gaming or simulation environments providing their harbor workers with experiential learning required it would simply be impossible to do because of the cost of machinery that could be destroyed, time and logistics of providing it, and of course keeping everyone safe.

The importance of Kolb's and Smed's *et al* experiential learning cycles and how it is supported or implemented via SBT. The pedagogy behind the use of simulation training for safety has been explained. Additionally most researchers follow the "10,000 hour rule" of direct practice is required for person to reach mastery level (Kulasegaram, Grierson, and Norman, 2013) and that "innate individual ability plays little to no role in explaining" how a person reaches mastery level (Ericson, 2004). Researchers have yet to establish if 10,000 hours of SBT is equal to 10,000 hours of training in the real environment for manufacturing or construction. The best estimation currently available is the 2014 report from the National Council of State Boards of nursing that stats for nursing SBT can substitute for 50% of the traditional clinical training (J.K. Hayden, R.A. Smily, A. Raij, S. Kardong-Edgren, P.R. Jeffries, 2014). Every field agrees that it is important that all industries take advantage of SBT because of its potential to improve (1) and make operations to be performed or practiced less hazardous and thus result in fewer accidents. Fewer accidents results in (2) no down time resulting in loss of production time. It also (3) reduces potential harm to people within the work zone due to chemicals or other dangerous materials being released due to an accident. Resulting in (4) better utilization of limited materials. Finally and most importantly it (5) reduces the number of casualties or deaths due to operator error.

HOW COULD SBT IMPROVE SAFETY

Since human error accounts for up to 80% of accidents in the top three industries that have been identified in this article being health, manufacturing, and construction (Garret and Teizer, 2009). Errors will never be 100% eliminated as long as human are involved in the process. However, appropriate and affective training can and will minimize the number and severity of them (Reason, 2000). In 2001 health services accounted for 24%, manufacturing 19.6%, and construction 12.5% or a total of 51.6% of all of the nonfatal injuries across all industries (Workers Health Chartbook, 2004). SBT provide safe training environment where trainees can repeatedly practice tasks needed, without worry of an actual physical accident happening if a mistake is made. Allowing them to learn from any mistake made, use trial and error, and eventually this will result in reactions that do not require them to stop and think “what should I do?” Instead, the training will kick in and reaction will be instinctual as their response is now second nature to them (Trybus, 2008).

LESS HAZARDS AND LESS ACCIDENTS

In 1970, the Occupational Safety Health Act made it management’s responsibility to provide workers with training that allows them to recognize hazards in their work environment. Thus providing workers with the tools needed to work safely and make decision based upon what is the best and safest choice. SBTS allow the user to train in a program that replicates the actual work environment, but without concern for “real world repercussions”, should a mistake be made (Eschenbrenner, Nah, Sau, 2008). SBTs provide workers with a risk-free, high-fidelity environments that replicates their actual work environment. If a trainee dies in the virtual world because the avatar forgot to wear all of the appropriate personal protection equipment PPE, it does not result in the company making the evening news. It also saves them thousands that the company do not have to pay to that person's family and/or to repair facilities, equipment, etc.. damaged in the accident. These training are experiential in that it requires that the user be active and engaged in the hands-on cognitive SBT learn by doing enviroment (Stanney, Hale, and Zyda, 2002). These training programs are designed to be flexible and provide training and/or customize it to the specific needs of the trainee. Focusing only on tasks that are part of their job and/or that is expected for a trainee in that position to come into contact with, not just on every single scenario that any worker with that company needs to know. This means that the trainee is able to practice specifically what is applicable to them and/or in something in the past has been low performance for them. Allowing for trainee to repeatedly practice and work towards the hours that help them meet that 10,000 hour rule for mastery. All of this results less accidents and thus less hazards in the work environment.

LESS DOWN TIME

Training employees is an expensive process for time, equipment, and facilities. In 2005 Boudrea and Ramstad explained that for companies to be competitive they must focus on finance, products or their market, and their human capital or trained workforce (2005). In todays' global economy products or market barriers have been broken thanks to in the internet and availability of goods to anyone. To have a strong financial base a company needs for the cost materials or goods to come in just when needed and to be delivered to consumers in a timely manner. Goods, products, materials, etc.. should never sit and wait to go out to the customer. So building and maintaining a quality, well-trained workforce provides companies the most sustainable advantage possible (Huselid and Becker, 2011). If the work force or operators are well trained, work happens at optimal efficiency and the service or product is provided in a timely manner. However, if the company losses that trained employee then that employee must be replaced and often training start all over again. That takes time, and that time negatively effects the company finance.

REDUCE HARM TO OTHERS

An example of how SBT have been used to reduce harm to the operators and/or people who will be in the production environment is BIM. Building information modeling BIM software provides a virtual environment that a safety engineer could use to identify and plan for potential safety issues (Hu and Zhang, 2011). An ideal situation for any work environment would be if it was possible to identify and have plans in place for safety of users in design phase and not leave it to the onsite managers during the production or construction phase (Manuelle, 2003). The RAPIDS Construction Safety and Technology Laboratory in the school of Civil and Environmental Engineering at the Georgia Institute of Technology has developed a rules based safety checking framework and algorithms (Zhang, Teizer, Lee, Eastman, and Venugopal, 2013). These designed rules 1) checks for holes in slabs, 2) checks for slab edges and their heights, and 3) checks for holes in exterior walls. Once these rules have been applied to the algorithm it then uses the BIM software to show the user where fall protection is needed in the virtual world. This allows the safety engineer to identify potential safety issues and show these issues using the virtual environment to best train workers on what to be cautious of and where the dangerous areas are. Showing just one way that SBT training can be customized to the dangers that the system finds which results in reduced harm to the workers and/or the public.

OPTIMAL USE OF MATERIALS

The RAPIDS system described above enables the safety engineer to estimate and schedule the safety equipment or material needed from week to week. Ensuring only what is needed is ordered and there when it is needed and thus strengthening the companies finances. Being able to bring in just what is needed, when it is needed saves the company time and money. Manufacturing companies use SBT to test their production process, allowing them to find the problems and correct them before the real production process goes into full operation. An example of this is V-Comm Digital Mockup program that Toyota used. This program found that 80% of the issues where assembly issues. By using simulation, instead of physical mockups Toyota was able to find these assembly issues and resolve them, thus shortening the production time by 33% and reducing product development costs by 50% (Erdel, 1995). Which results in a properly trained and prepared safe work force or operators who are able to perform at optimal levels, the company can then deliver their product to their market quicker than their competitors, and this all strengthens the company's financial base.

LESS OPERATOR ERROR

Operator error is most commonly caused by lack of training, lack of time for experiential learning to happen by the application of what is learned in the training, and skill decay. Arther, Bennett, Stanush and McNelly probably best explain skill decay, as what happens when the operator does not perform or practice the skill (1998). The operators or work force must receive proper training, this training amount varies by the operators prior knowledge or ability to learn new things. It is best to adapt the training to what is needed by each person, so that time isn't wasted in training not needed, instead training focuses on items that are a struggle or new more complicated training. For the training to truly stick or become second nature for the operator, there must be time given to learn experientially by applying the skills. Something that is often hindered by not having enough trainers, material, equipment, facilities, or that the job being performed is extremely dangerous. To stop skill decay companies need to be able to have refresher training on skills they don't perform all the time, which is hindered by the same items as the initial training. SBT adapt the program to the skill level or need of each person being trained. Providing an environment where the person being trained can quickly and easily reset and try again should mistakes be made and a step is failed. Additionally refresher training is just as accessible and can often be done from anywhere. When this is all combined together, the operators are better trained, their skills have had time to start to become second nature, and providing the trainee with a huge lead on the 10,000 hour rule over someone who has only had limited traditional hands on or OJT training.

CONCLUSION

Simulation training will most likely never replace traditional learning by doing on the job, at least not in our lifetime. Who knows future simulations may get to the level or realism as portrayed on popular Sci-Fi shows likes the holodecks on Star Trek. Even if SBTs never reach that level of realism, they still provide a safe method of training to help the operator get to the 10,000 hour rule. SBTs allow the person being trained to reset when a mistake happens quickly so that training can begin again immediately. Something that when a mistake is made in the real world it can often take hours or days to reset. The real world mistakes made in training will have the company in the news for all the wrong reasons. Whereas if an accident happens in SBT it doesn't end up on the 6 o'clock news. Future studies need to be conducted to find out how SBT hours compare to real world hours for manufacturing and construction. So that the ideal combination number of SBTs and real world application hours can be calculated and then followed. So that (1) operations that need to be performed are much less hazardous and thus result in fewer accidents. Resulting in (2) no down time or loss of production time. Lessening the (3) potential harm to people within the work zone due to chemicals or other dangerous materials being released due to an accident. The best (4) utilization of limited materials. Finally, and most importantly, it (5) a significant reduction in the number of casualties or deaths.

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