Use of simulators together with virtual and augmented reality in the system of welders' vocational training: past, present, and future

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Abstract. The article discusses the theory and methods of simulation training, its significance in the context of training specialists for areas where the lack of primary qualification is critical. The most widespread hardware and software solutions for the organization welders' simulation training that use VR- and AR-technologies have been analyzed. A review of the technological infrastructure and software tools for the virtual teaching-and-production laboratory of electric welding has been made on the example of the achievements of Fronius, MIMBUS, Seabery.

The features of creating a virtual simulation of the welding process using modern equipment based on studies of the behavioral reactions of the welder have been shown. It is found the simulators allow not only training, but also one can build neuro-fuzzy logic and design automated and robotized welding systems.

The functioning peculiarities of welding's simulators with AR have been revealed. It is shown they make it possible to ensure the forming basic qualities of a future specialist, such as concentration, accuracy and agility.

The psychological and technical aspects of the coaching programs for the training and retraining of qualified welders have been illustrated.

The conclusions about the significant advantages of VR- and AR-technologies in comparison with traditional ones have been made. Possible directions of the development of simulation training for welders have been revealed. Among them the AR-technologies have been presented as such that gaining wide popularity as allow to realize the idea of mass training in basic professional skills.

Keywords: simulation training, couching programs for welders training, hardware and software for simulation training.

1 Introduction

In order to make professional preparation more attractive and engage in a new generation of skilled workers, computer-centric technologies, such as computer training devices and simulators, are increasingly used. These are computer applications imitating the behavior of real objects, processes, systems and their interfaces in a variety of conditions. Having gone a long way in their evolution, now training devices and simulators build on the technologies of virtual reality (VR) and augmented reality (AR). They are generally recognized to organize professional training in line with principles of visualization, gamification, task centered and activity approaches.

In the system of training and retraining of qualified welders, thanks to the rapid development and cheapening of computer technology and progress in the field of AR- and VR-technology, machine vision, artificial intelligence systems and whatever, the training simulators are widely used. This makes it possible to increase the efficiency of vocation training by several orders of magnitude in compare with the traditional form of welders training. According to the estimates of flagships this market segment, in particular Fronius, Seabery and others, this allows to prepare certified welders more, then 34%, to reduce the training period by 56%, decrease the cost of laboratory work by 68%, to diminish CO_2 emissions to the environment, to save considerable resources and materials, to avoid physical risks for students in 84% of cases [31].

The programs of welding training that based on simulators are being created and implemented everywhere. Such programs are also patronized by the Ministry of Education and Science of Ukraine, which started 50 modern training centers for qualified welders' preparation. During 2017-2018, they received government assistance on a tender basis for the modernization of the material-and-technical and training resources. By means of this program three vocational education institutions have purchased modern virtual welding devices [41].

Although the problem under investigation couldn't call current, a lot of teachers and masters of vocation training are not well-versed in this field; they insufficiently master of the simulation training with use AR- and VR-technologies.

The ***purpose*** of the publication is to review the most common hardware and software solutions for the simulation training of welders, as well as analysis of the advantages and disadvantages of such training using AR- and VR-technologies.

2 Materials and methods

Should take into account, the performance and quality of welding depend on the used welding equipment, the materials, the welding modes, and last but not least – from the welders' qualification, the level their theoretical knowledge and practical skills, as well as the degree their readiness to be make quick and reasonable decisions. Such qualities are possible to obtain only due to the long-term training. However, this process can significantly accelerate if ones use of the simulators and training devices.

The issues the methodology on working with emulator programs and simulator ones are investigated by Albert A. Azayan [15], Ihor S. Chernetskiy [6], Muhammet Demirbilek [7], Roman M. Horbatiuk [8], Arnold E. Kiv [14], Oleksandr H. Kolgatin [3], Maiia V. Marienko [19], Yevhenii O. Modlo [25], Vitalii Ya. Pazdrii [27], Halyna V. Popova [18], Irina A. Slipukhina [33], Vladimir N. Soloviev [32], Illia O. Teplytskyi [38] and others.

General aspects of the application of AR- and VR-technologies in the simulation studies organization are being disclosed by Victor V. Aulin [1], Platt Beltz [2], Yevhenii O. Modlo [23], Serhiy O. Semerikov [24], Viktoria V. Tkachuk [39], Denis O. Velykodnyi [1], Yuliia V. Yechkalo [36] and others.

The state-of-the-art successes in the design of the ideology of simulation training together with use AR-and VR-technologies have contributed to the development of the theory and methodology of vocational training, which is being developed by Christian Dominic Fehling [9], Mario Heinz [13], Dieter Mueller [26], F. David Rose [28], Lina M. Rubalko [29], Kai Schmudlach [30], Huiying Zhao [43] and others [16].

Well-grounded approaches to the use of AR-and VR-technologies for the design of training simulators in the welding industry are being elaborated by such well-known companies as Amatrol [42], Fronius [11], Miller Electric [21], MIMBUS [22], Seabery [31], Tech-Labs [37], Virtual Logic Systems [40], etc. The developments that have been started by these companies are being widely used for simulation training in a lot of countries around the world. Researches in the area of engineering psychology concerning formation of the most important competencies in qualified welders while the use of these firms' simulators are being carried out by Ryan G. Anderson [4], Alex P. Byrd [4], Siu-Ju Chen [5], Yukang K. Liu [5], Richard T. Stone [4], Yan-Ming Zhang [5] and others. It's determined the prototype and analogue of modern training technologies for welders is the methodology of the simulation training for medical staffs [35].

3 Results and discussion

3.1 Features of the virtual teaching-and-production laboratory of electric welding

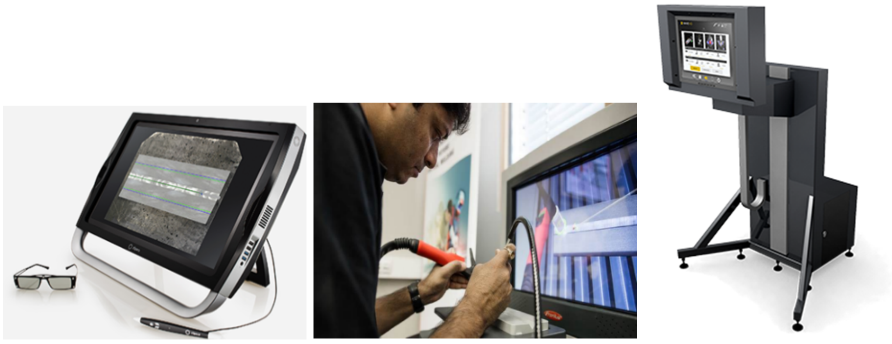
It should make a point that the ***simulation*** is a reproduction of a system or process purely virtually. Typically, imitation refers only to certain properties, capabilities or functions, and in the extent that is necessary within the framework of set tasks. As to the participant of the simulation process, the work is being done by him/her like in actual fact; at the same time the simulator's functional part is virtual either completely or almost completely.

In the medical education system the simulation training signifies an important role as one enables a future specialists to develop their skills and abilities without risk for the patient. Simulation is treated as a technique (but not a technology) allowing either to replace or to enrich intern's the practical experience by means of an artificially created situation. Simulation reflects and reproduces the problems taking place in the real world in a fully interactive manner [12].

Simulation training is a compulsory component of vocational education that uses a model of professional activity. It enables future specialists to carry out their professional activity or its element in line with professional standards and / or rules with the help of "immersing into a particular environment" [35, p. 36].

The equipment kit of the virtual training laboratory allows accelerating the learning process of welding technology (and therefore reducing costs), improving the quality of the specialists' training. These are the computer based systems imitating the welding equipment and tools, as well as typical welder scenarios. The simulators usually build in accordance to the recommendations of the International Program of Welders IWS, the Programs Sense AWS, the German DVS Media, CESOL, etc., and based on American ASME and European ISO standards [22].

On the whole, the wide variety of equipment offering for the virtual educational and production laboratory can be divided into three categories. One is an educational solution (Fig. 1a), another is a transportable industrial solution (Fig. 1b), yet another is a heavy industrial solution (Fig. 1c).



a) b) c)

Fig. 1. Main types of equipment for welding training laboratory on the example of products of companies MIMBUS (a, c) [22] and Fronius (b) [11]

Both the additional means of VR and AR (3D glasses, welder's gloves and helmet) and equipment (torches, rack, table, workstation, coupons, holders and whatever) use in various combinations for realize the assigned tasks of vocational preparation. This allows for virtual welding of various details unrestricted that the protective devices or missing welding equipment can give at the time of work in a real environment.

Fig. 1a demonstrates the capabilities of Z-Space technology. For its implementation, it is necessary to have only a monitor with a touch screen, stylus, 3D-glasses. The software includes a wide range of training exercises by means of a stylus with a view to learning the processes that most commonly use in welding production. There are simulations of Manual Metal Arc (MMA) welding and Metal Inert / Active Gas (MIG / MAG) one in this set. The goal of such a training device is mastering by trainees the theoretical knowledge and development their welder's important qualities, such as concentration, accuracy and agility [22].

Fig. 1b presents an industrial solution with a full set of tools including the capability to Tungsten Inert Gas (TIG) welding and simulating short arc, spray and pulse. There are a touch screen monitor, a welding burner, a surveillance device and a work surface. Most of the known simulators of this type are equipped sound devices for imitation the tones that arising while welding, as well as for the generation of warning signals in the case of improper actions by the trainee. All of this can be located in a lightweight and portable case. Work with the simulator takes place in real time with a burner that completely simulates the welding process. To determine the quality of the welding and the shape of the weld, monitor the position of the burner and the speed of its movement the sensitive sensors are used. Furthermore the system can analyze the dependence of the shape and the quality of the made seam from the input initial parameters of welding [22; 37].

Fig. 1c shows an industrial solution for a virtual training laboratory for welding including all of the options that described above. It is an integrated robot weighing about 200 kg with a computer controlled mobile display; a set of burners and equipment for different types of welding and various positions whiles the work. The system is protected by locks, an emergency stop and an inverter, that enables the trainee to perform a significant amount of exercises autonomously and with significant level of safety [22].

3.2 The simulation of welding with AR-technologies

Prima facie, VR-technology is rather as promising for welders' preparation then AR one. However, AR, using elements of the real production environment and imposing on it a certain proportion of virtual information, can significantly improve the efficiency of simulation training process.

The equipment's kit offering for the implementation of this idea, almost fully simulate the real welding machine. Fig. 2 presents the main elements of this technological solution developed by Soldamatic and Lincoln Electric. As can be seen it includes:

- the real torches with in adapted tip with markers for AR detecting;
- the consumable electrode sticks and torches with grip that have a mechanism imitating electrode's burning out;
- the simulator based on real sources of welding current that made in either mobile or industrial versions; it supports all four manual arc welding process (TIG, MIG, MAG, MMA);
- the AR helmet, it is an analogue of a real welding mask that can reflect the surroundings of your welding space as well as simulate the future result;
- the PVC coupons to simulate work with different welding surfaces;
- the torches to perform high-quality welds of the type Gas Metal Automatic Welding (GMAW), Gas Tungsten Automatic Welding (GTAW) and Submerged Metal Automatic Welding (SMAW).

The system can also include volumetric models for simulating welded joints and welding positions, a display, a torch tracking system, an audio device for simulating sound, and whatever. Thanks to ergonomic welding torches and typical details of the simulator's kit, one can safely learn welding while use different parameters. The four functional packages that supply with kit allow one to work through four process options – TIG, MIG, MAG, and MMA [11].

The control center is provided access to several functions, such as: a welding track; distance between sheet steel and nozzle; the speed of the welding, the orientation and the welding angle, the time of the exercise. During operation by means of the electromagnetic field and sensors the device transmits the direction of the torch, the distance to the product and even weak hand movements. An additional sensor on the AR Helmet makes it possible to see the product in all angles on the touch screen or 3D-glasses. In the end, one can analyze the result obtained by evaluating the length of the welding arc, the speed of the welding passage, the angle of inclination during the welding passage, the angle of the torch, the distance to the workspace, the pores into the welded joint, the burrs during welding, the cuts, the etching, the welding of the root and whatever [37].

a) b)

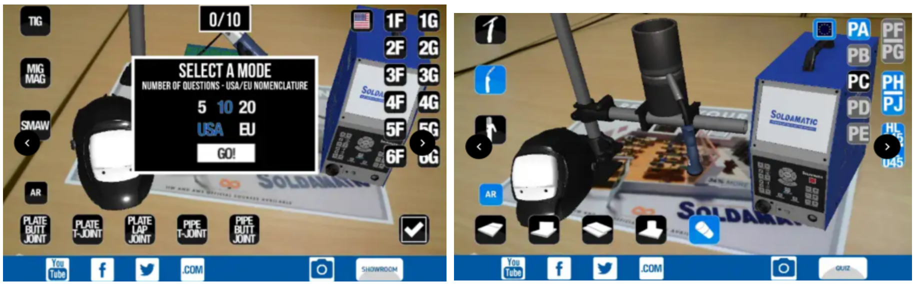
Fig. 2. A set for the organization of Augmented Training by Seabery (a) and Lincoln Electric (b), [31; 37]

At the moment, AR-technology in the training of welders are widespread to mobile applications, and, take note, in most cases, they are either free or conditionally free. The apps can run on an ordinary smartphone, a tablet PC, and so on, it is enough so that this gadget has a reader device and a touch screen.

Soldamatic AR is a freeware app to test the theoretical knowledge of welders offering by the Play Market (show Fig. 3). To attach an AR to the surface as a marker one can use whatever, even a business card.

As you can see, it almost simulates the equipment that was given on Fig. 2a. Thanks to AR-technologies it is possible to see on the gadget's screen the various types of welding equipment, to consider it from different sides, to simulate the work fully with a real welding machine, as well as to check the theoretical knowledge of three topics (types of welding, types of welding joints, spatial position of the welding unity).

In the upper left angle of the Fig. 3a you can see symbols of welding types: TIG, MIG / MAG, MMA. Below them AR cursor is presented, if you are touching it, the markers are added to the product. The following one can see the types of welding joints, such us: butt, T-shaped, lapped, pipe-plate, pipe-pipe ones. In the upper right angle in Fig. 3a there are marks of the standards of the spatial position of the welding.



a) b)

Fig. 3. Soldamatic AR Dialog Box

Welducation basic is a free game virtual welding simulator developed by Fronius. It can help arranging work on training and controlling knowledge of welders.

The simulator offers like variants for work the AR- or 3D-technologes. In any case the Fronius logo is a marker for fixing the augmented reality.

As you can see from Fig. 4, the menu on the choice of welding connection is offered on the right side. App's menu proposes: bead on a plate, fillet and single weld. As soon as user has chosen a type of welding connection in the next window a burner simulator will appear and one will be able to start simulating the welding process. Over and above the app offers 50 questions with four variants of answers that to be solved for a certain period of time.

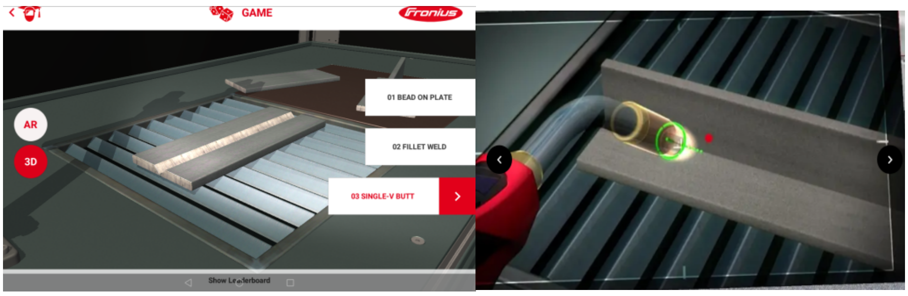


Fig. 4. Work in Welducation basic in simulator mode

Unfortunately, within the publication it is impossible to disclose all the existing proposals from producers for the organization of welders' simulation training based on AR-technologies.

Far-reaching prospects in this area are discovered in using SMART-glasses technologies. These glasses are equipped with technical features that provided by the processor. Ones can be manage in several ways, including buttons, sensors, voice or gestures, or using a connected smartphone and others devises. They are also able to perform various manipulations with the incoming information, as well as record and transmit information through the Wi-Fi system. As you understand, this is only the beginning their development way [20].

The device weighs about 400 grams and it is fully compatible with the existing analogues in its own technical and software characteristics. The glasses are completed with several 120 degree cameras, screens, microphones and speakers that facilitate the transfer of the enhanced image AR and create a natural sound effect from the object [20].

According to experts mean these devices or their analogs may be about to squeeze smartphones out of the market and make significant changes to the ideology of simulation training. What's more, we understand that technologies AR that implemented by virtue of mobile devices and smart-glasses have become a serious alternative to Z-Space technology in the welders' preparation process.

However, it should be noted the simulation training to be carried out according to a certain methodic and its structure must not depend on the type of used equipment.

3.3 Augmented training as a comprehensive educational and technological solution

The creation of welder simulators and building on their basis training programs using AR- and VR-technologies has become the answer to the issues naturally occurring in the vocational training process. As it is known, welding is a harmful high-temperature procedure which with the formation of molten metal spray, with ultraviolet radiation and with the evolving of welding smoke and aerosols. During a training process a lot of samples are being processed that need to be further disposed of, furthermore the materials and energy are being consumed. At the same time there is a lack of qualified instructors for training and retraining of welders [11].

The ***welding's simulator*** is a device imitating of movements of a welder during welding that shows the welding process and the obtained outcomes [37].

As soon as the AR-and VR-based welding simulation launch, a lot of steps have been taken to improve hardware and software solutions for simulation training. The main achievements in this direction are the creation of the most realistic three-dimensional weld pool and human welder response models that were built by observing the actual work of the welder. Researches in this area of expertize have been realizing around study of the reactions of welders and the work of automated welding systems, which are able to change the parameters, whiles the process, depending on the type of the weld pool [4].

Investigators of this problem have discovered and originated a neuro-fuzzy logic of the human welder behavior, and compared reaction an experienced welder with it reproduction by automated welder machines. Due to this fact the machine algorithms were created that can manage a simulation training through feedback systems. Initially, the visual feedback devices were made for VR trainers, but they were not as effective for vocational training as a systems basing on vibration sensors on the welding helmet. It is these devices that have made it possible for trainees to immerse themselves in a VR environment and organize simulation exercises [4; 5].

All companies offering hardware and software for simulation welding training formulate their proposals on a modular basis. This approach allows, first of all, to consider carefully all the pros and cons, to selection the most necessary equipment and software, to save money, to create a long-term plan for further equipping the training virtual laboratory, and, at the end of the day, to choose the most appropriate training programs.

Soldamatic's ideologues and managers have been given a definition of Augmented Training as a comprehensive educational and technological solution that are implemented a new paradigm of professional, technical and production training, using innovative technology, resources and techniques based on simulations with VR and AR, and exploring their management (Fig. 5) [31].

Fig. 5. Soldamatic Augmented Lab [31]

The simulator is built on the implementation of a task-oriented approach in training and contained a powerful library of exercises that designed for any equipment, welding systems or their subsystems. It is a reliable tool for analyzing and evaluating performance of typical exercises, which enables monitoring of the effectiveness of the trainee's work [31].

The simulator cover a wide range of tasks, such as: forming of effective welding skills for beginners and either improvement or acquisition of new skills in certified staffs; adaptation to the specific production of new welding technologies; receiving qualification requiring for the operation and programming of automated and robotized welding systems [37].

In general the technology of simulation training consist five consecutive stages [35, p. 38-40]:

1. It is entrance testing. According to its results, a program and a training route for the welder are formed.
2. It is briefing that conducted with the analysis of theoretical material and fixing the "key" provisions.
3. Work with computer training devices and simulators.

Supposedly the choice of simulation technique is mediated by the trainee's previous practical experience as well as a set of procedures that welder would like shaping. In welders' vocation training it can be used the following leading systems, such as: objective, operational, motor-training, subject-operational (complex) and design-technological ones.

The work takes place in *two stages*. The *first stage* is a theoretical training mode consisting of 3 sections. The so-called "Ghost", a virtual teacher, gives a piece of advices to trainee. In this manner the best technique for performing the exercise is indicated. The Ghost presets the optimum welding speed, the distance to the workspace and the angle of inclination of the welding torch. The colored signals on the screen, similar to the signal of the traffic light, and the realistic welding sounds show to trainee the current status of the process, fixed the errors and / or correctly performed actions. The visualization of the welding process and trainee's hands can be traced on the built-in touch screen as well as to broadcast in a larger format through a projector or a TV screen. In this mode the corrections in welder's actions can be made [11].

The *second stage* is a simulation that includes 2 sections. Initially, the beginner trains to perform welding in the real situation – unassisted of so-called Ghost, a virtual coach. Then the trainee himself may be about to set the necessary parameters (Fig. 6). This well-designed learning structure always provides the high results [11].

Fig. 6. Fronius simulator menu [11]

Depending on the composition of the procedure that forming, the simulator can provide a consistent execution of exemplary action at a slowed pace; then to fulfilment it at a natural pace with a demonstration of speed and correct execution. Finally, one arranges a series of exercises for working out simple abilities and their automation. After skills' shaping in, usually tasks are offered; they based on the most probable professional situations and made in order to include a new skills in the spectrum of already formed competences and their transfer to new non-standard situations [17; 10].

4. It is Debriefing. On this stage the welding quality and fixedly attached of levels process can be analyzed and verified. The simulator can detect the welding defects

and establish their causes, to reproduce the movements of the torch during simulation and to save data. The training process can be printed, if necessary, for evaluation by an instructor or whoever (Fig. 7). The system evaluates the welder's skills basing on five welding parameters; these are position, arc length, work angle, travel angle, and travel speed [34].

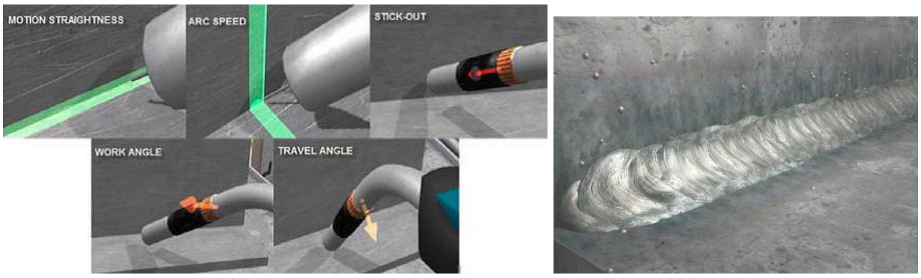


Fig. 7. Possible results of debriefing [34]

5. It is summing up of work and the test control. As has been shown in a lot of investigations the objective system of estimation of welding within the limits of simulators is developed allowing estimating actions of the trainee under certain parameters. The program automatically generates a score sheet including an assessment of each trainee's individual performance. It allows getting information about that must to be repeated and that to be focused on [34].

This system also enables to compare trainees' grades and track their skills upgrades.

4 Conclusions

Simulation is a technique that allows either replace or to enrich the trainee's practical experience with the help of an artificially created situation reflecting and reproducing problems that take place in the real world in a completely interactive manner [12].

Simulation training is a compulsory component of vocational training that uses the professional model to enable everyone to perform actions effectively and productively and in accordance with professional standards by means of immersing in a specific environment [35, p. 36].

For one's turn simulation training founding on AR- and VR-technologies has a number of advantages. It allows improve the educational process, to accelerate the transfer of knowledge and experience, and also to take up to new qualitative level the vocation preparation and retraining of welders, to facilitate one the process of transition to other types of equipment and technologies.

Simulation training technology in generally consists of five consecutive steps [35, p. 38-40], such as: Initial testing → Briefing → Work with simulators and simulators → Debriefing → Summary of work, test control.

In this time welding simulators are complex systems of visualization, imitation and simulation including both computer programs and physical models, based on special methodology. The simulator trainings and the coaching programs are oriented both on the development of trainee's practical skills with their theoretical study. They are designed to prepare the trainee for making quality and fast decisions in the future professional area. Visualization of educational material and practical actions facilitate its perception and assimilation, built-in gamification enables to push up the motivation and emotional adjustment of students on several orders. Such programs are able to progress along together with as well as those taught and trainees [2].

Simulators allow not only training, but also ones to investigate the responses of the human welder's during the simulator's work, build neuro-fuzzy logic and design automated and robotized welding systems.

The only disadvantage of such simulators is too much high their cost. One way to look at this issue is a choose alternative from the standpoint of simulators' cost and also its benefits and advantage. In fact, if the simulation is closer to the actual operation of the welding equipment, then cost and potential benefits are higher. However, on a case-by-case basis it should to be guided by specific teaching and production tasks. In any case, during the first year using the simulators they will be able to pay for themselves fully.

Significant prospects are observed in the widespread introduction of mobile educational AR apps and SMART-technologies in general. These devices or their analogs is seems may soon squeeze smartphones out of the market and make significant changes to the ideology of simulation training for welders.

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