A 3D Learning Tool for a Hydroelectric Unit

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ABSTRACT: This paper presents a new learning system for a hydroelectric unit of energy (HUE) by using desktop virtual reality (VR) techniques. The software offers the possibility to understand the relation between the physical structures of a UHE, through computer simulations, graphical outputs, and animations. Three learning courses are offered. Educative is the first course that allows familiarizes the student with the structure and with the constituent pieces of a HUE, as well its general and technical information. The second course, maintenance, uses the learning approach based on practice and offers different learning levels, divided into three modes: automatic, guided, and exploratory, in which these modes are accessed according to the acquired degree of knowledge by the user in relation to maintenance procedures. The last course, operation learning, allows the student to visualize the operation of HUE during a certain event as the electromechanical dynamics of the turbine-generator assemblage in the virtual world by the visualization of several requisite conditions before the startup procedure of HUE. Finally, it was made a performance comparison between the Electrical Engineering students which used the learning module with the case where that was not adopted.
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INTRODUCTION

The challenge of electrical engineering courses, specifically the discipline system of power is to give students an understanding of physical phenomena of energy generation, and offer comprehension of the functioning of the main components of a generating unit of energy, such as generator, piping, and turbine [1].

Usually, teachers of the discipline of power limited only to traditional lectures, and few of multimedia materials are used to explain complex concepts and abstract the phenomena of energy generation, and students rarely have contact with equipment and physical structures of a generating unit, the majority of students never visited a hydroelectric, the which has difficult access and can pose risks to visitors.

To reduce the gap between the real experience and theoretical concepts in the area of systems of power, there are projects for virtual reality (VR) systems [2,3], which aims to view and handle easily internal structures of a generating unit of energy.

The general aims of VR applications in the studies of hydroelectric unit of energy (HUE), are:

- To relate the theoretical and practical aspects of teaching.
- To ensure that students obtain sufficient information on the nature and methods to use the most important HUE components.
- To improve the self-learning process and induce a critical analysis of the results.
- To provide an active and more personalized education to motivate the students.

An important advantage is related with using VR technologies, which allows for more realistic and detailed representations of topics, offering more viewpoints, and more inspection possibilities compared to 2D representations. In many educational contexts, this can be crucial to better understand topics [4].

The present work proposes a educative system for the assembly and disassembly procedures of pieces contained in a HUE using desktop VR techniques, attending to the main requisites of virtual learning that are available in the Refs. [5–9]. The learning environment is comprised of (i) the Educative course, which to make possible the study of a hydroelectric generating unit, (ii) the Maintenance course, that corresponds to the learning procedures for the maintenance of the sub-units of the HUE, and (iii) the Operation course.

The Potential of Virtual Reality in Engineering Education Section presents a contextualization of VR and its application in

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engineering education. Study of a HUE Using Non-Immersive VR Techniques Section shows the study proposition of the learning system of a HUE using Desktop VR techniques. Courses on VGU System Section presents the courses related to educative, maintenance, and operation. System Evaluation Section provides an evaluation of the system and, in Conclusions Section, final considerations for the conclusions are proposed.

THE POTENTIAL OF VIRTUAL REALITY IN ENGINEERING EDUCATION

According to studies by Boud et al. [6], the acquisition of abilities is divided into three stages: the cognitive stage, in which people learn the procedures and basic properties of the object; the associative stage, in which the procedures and knowledge about the objects function as part of the sequence of actions; and finally, the qualified stage, in which the sequence of actions are combined according to a specified standard of activities.

Each stage requires a decrease in the level of conscious control. One of the discussions in Boud's work is that the activities that are carried out by traditional methods are based on the cognitive stage, whereas VR leads the student to the other subsequent stages, thus, offering the user superior stages of ability in relation to conventional training.

This potentiality of VR is motivated by the favorable experiences resulting from education in engineering [10,11], visualization of complex virtual environments in CAD [7,8,16], its usefulness in assembly processes [5,8], and applications of training based on the learning-by-doing approach [2,3,9,12]. This approach encompasses two vital elements: the personal experience made possible by simulation of the real-world environment of (using a graphic user interface or VR or both) and the training process initiated by following the guidance of the instructor.

During the researches into the subject, VR applications related to both immersive and Desktop training were observed. In spite of the fact that immersive application offers a high level of interactivity and realism, it nevertheless requires advanced hardware and software for its implementation, limiting its use in various applications and inhibiting its popularity. Moreover, the ergonomics of most non-conventional devices is still a great problem that prevents the use of immersive VR into a widely accepted tool among users and researchers [12].

STUDY OF A HUE USING NON-IMMERSIVE VR TECHNIQUES

As a case study, the HUE plant of the Tucurui hydroelectric was investigated. This plant is located in North Brazil, at 3 50′ S latitude and 49 30′ W longitude of Brazil over the Tocantins River in Pará State. The Tucurui plant has an installed potency of 8,370 MW and has 23 HUEs. It is the second biggest Brazilian hydroelectric project and the fifth biggest in the entire world.

For implementation of the virtual environment of the HUE plant of the Tucurui hydroelectric, a tool called the virtual generator unit (VGU) was developed, based on Desktop VR techniques. The HUE pieces are formed by CAD models, organized in a hierarchical graph of scenes, and their corresponding database is composed of files in XML format (eXtensible Markup Language) (Fig. 1).

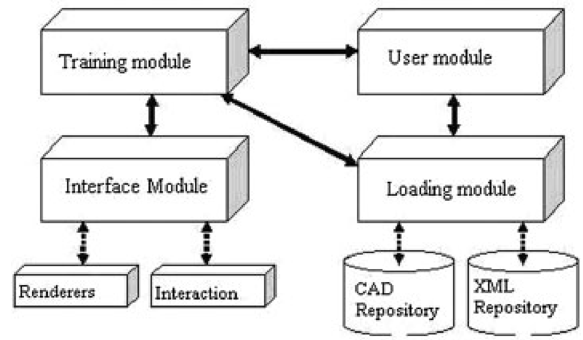

Figure 1 Diagram of VGU architecture.

The main module of the system is the Training Module, which manages all the activities of the other modules, and it is the intermediary of data changes in the system. The training module has rules of assembly planning, executes assembly and disassembly sequences of pieces and, finally, realizes the evaluation of the trainer's performance on procedures.

The loading module may allocate in memory the pieces in CAD, using 3D Loaders. This module also loads the users and pieces files, which are stored in XML files. The users files have descriptions such as: user name, password, evaluation, task status, as well as description pieces files, such as: piece name, physical data, environment position, and others.

The user model is responsible for the management of trainer's referent data, registering personal information such as name and password, as well as evaluation information of training module, such as trainer's performance and conclusion status of maintenance procedures.

The interface module promotes the interaction between the system and the trainer, by two sub-modules: Rendering sub-module, responsible for 3D virtual scene loading with HEU pieces, and interaction sub-module, responsible for the captivation of users' stimulus, by mouse or keyboard, and for responding through textual means or in virtual environment.

For implementation of application VGU, was used the DELPHI language and the components Open Source GLScene [13]. GLScene is an OpenGL based 3D library for Delphi. It provides visual components and objects allowing description and rendering of 3D scenes. The Hardware configuration used was a PC with processor Core 2 Duo E4500 and 4 GB of Memory RAM and graphics board NVIDIA QuadroFX 1100 (128 Mb).

COURSES ON VGU SYSTEM

The VGU has three main courses. The first, educative course, offers to the student the opportunity to view and navigate on a structure of a HUE. The second course, maintenance, is a learning based on learning-by-doing and it offers different levels of learning and evaluation to the technicians. The third course allows the student to visualize the operation of the HUE during certain events as the electromechanical dynamics of the turbine-generator assemblage in the virtual world during the visualization of several requisite conditions before the startup procedure of HUE.

Educative Course

In this module the trainee can pick a section (piping, turbine, or generator), disassemble it and assembly it back again, step by step, and visualize the used mechanical part (being able to interact at will) interpreting textual information on it. Can make HUE parts become transparent to visualize interior sections, navigate through the virtual world and choose five different view angles to be positioned in relevant places for a better understanding of the HUE system.

The interface is divided into: information on the hierarchy of parts and learning in the upper part, buttons of action in the left side, virtual world in the center of the screen and the exhibition of text information in the inferior part (see Fig. 2).

From Figure 2 the trainee can pick with the mouse one of the HUE sections (piping, turbine, or generator). Following a sequence, the Figure 3a shows the result of the turbine selection by the user.

The Figure 3b shows the selection of the Turbine Distributor system, which is part of turbine. This process can continue until the last constituent part. In each selection, the user goes down a level in the hierarchic tree of parts and the information on the new part or set of parts appear in the text area. At any time the user can return to the previous level selecting the ''back one level'' button.

Maintenance Course

The learning environment in VGU uses Desktop VR resources permitting the user to virtually carry out the maintenance procedures, working through the assembly and disassembly operations of the pieces and equipments of HUE, on the basis of the operation and maintenance manuals of the turbine provided by ELETRONORTE.

Following the scheme of learning by steps, in accordance with the trainee's degree of knowledge, as contained in study by Blumel [8], the course has three learning modes: automatic, guided, and exploratory. These modes are accessed on the basis of the degree of knowledge of the user in relation to maintenance procedures.

Automatic Maintenance Mode. In this mode, an automatic animation of the steps in the maintenance procedure is presented as an orientation technique for the learner. According to the type of maintenance chosen by the trainee, the animation is carried out, and the procedural instructions are shown in the text area interaction with the virtual environment is the least possible in this mode. The maintenance procedure is developed through an animation that shows the assembly and disassembly movements of the piece, and the trainee controls the entire process.

This learning aims to present the pieces that are involved in the maintenance and to show the correct position of the technician in the HUE structure and the correct sequence in which the pieces must be manipulated. An animation example of the disassembly maintenance procedure of the superior trunnion plug is provided in Figure 4a,b.

The Figure 4a shows the beginning of the assembly procedure. In the bottom part of the text screen, the system asks the user to click on the ''Animation'' button to start the procedure, and the image in the center of the screen shows the removal of the eccentric pine (inside the vertical circle) and the screws from group A (inside the horizontal circle). The remaining consecutive steps of the maintenance procedure are shown in the Figure 4b–d.

The VGU system offers two types of visualization for this maintenance step. The first is the external superior vision of the Cone, which allows the user to visualize the withdrawal of the lid of the cone floor from the outside, and, from the opening in the lid of the floor, the user can manipulate the pieces in the maintenance area (see Fig. 4b). Figure 4a shows the second type, namely, the inferior lateral view inside the Cone.

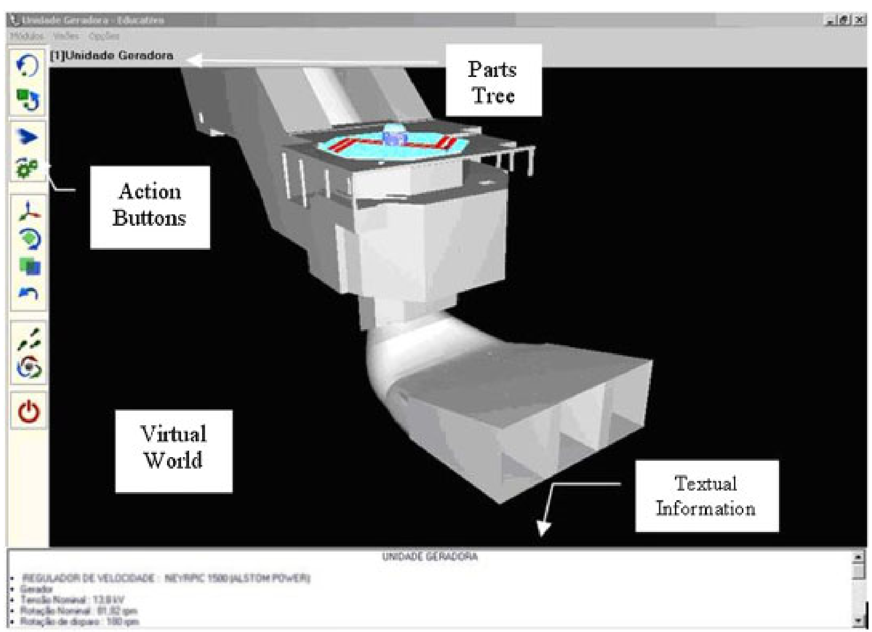

Figure 2 System Interface with its main characteristics. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

a

b

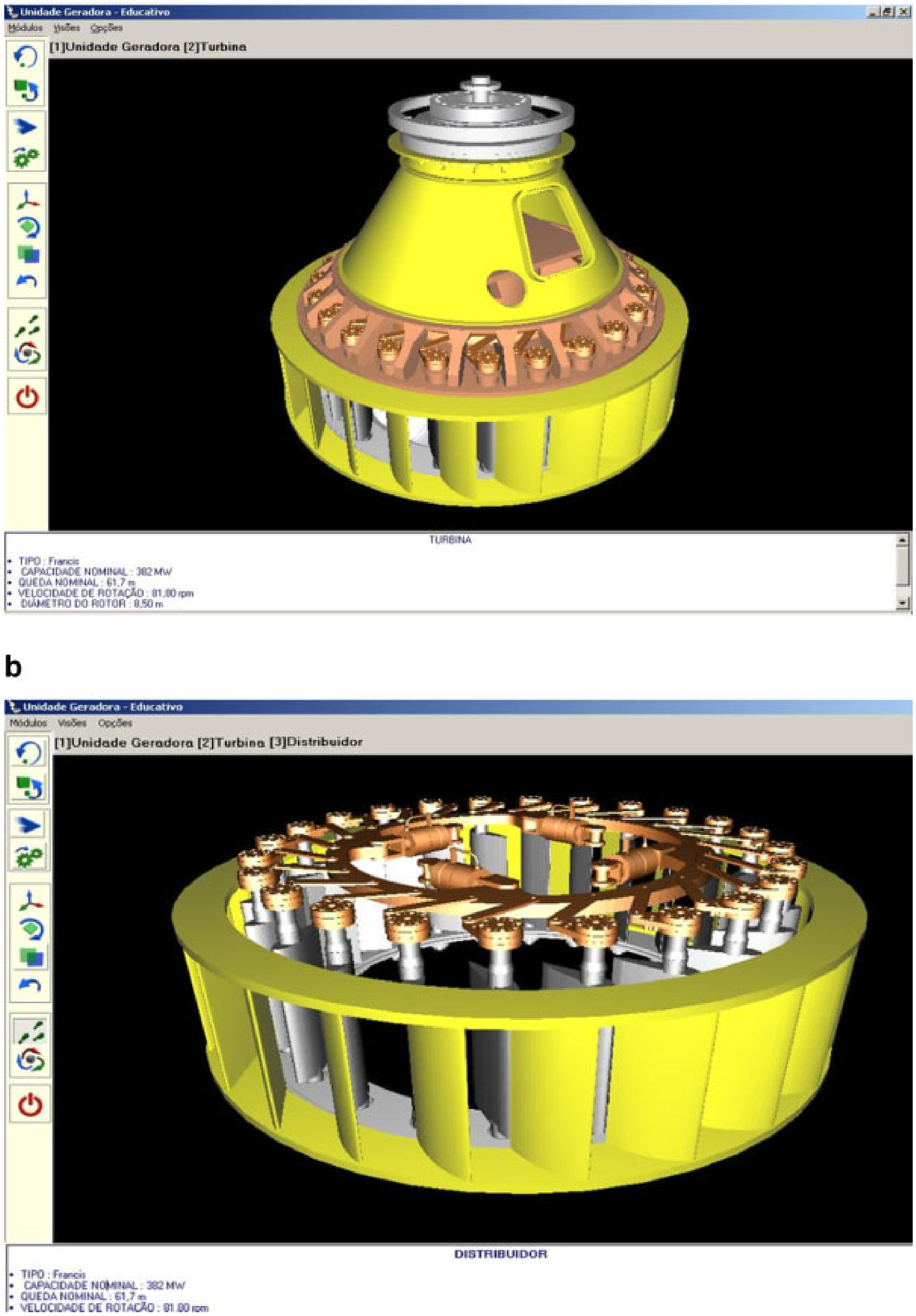

Figure 3 (a) Turbine selected by picking over VGU. (b) Turbine Distributor System selected in level internal. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Guided Mode. In this learning mode, the system guides the user by commands that detail the maintenance procedures. In contrast to the automatic mode, here the trainee has to manually select the maintenance tasks using the mouse, which allows the selection and movement of pieces through picking events (virtual choice of objects by clicking on the mouse). When a piece, which is part of the maintenance context, is clicked on, a message informs the name of the object in the scene and, simultaneously, the instructions related to the object are shown in the text inferior area.

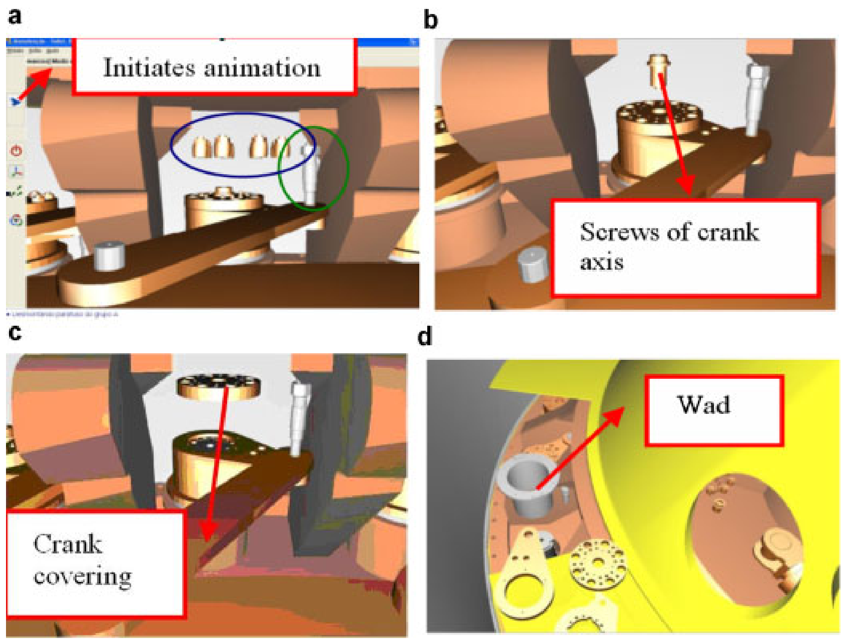

Figure 4 (a) Beginning of maintenance animation of superior trunnion plugs. (b) Removing the screw of crank axis. (c) Removal of the crank covering. (d) Removal of wad. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

When a piece is moved in the correct sequence, a positive message is shown, informing that the piece was assembled or disassembled successfully. To convert the features of virtual pieces to reflect the real world, the collision-detection property is used, with the aim of preventing the user from mistakenly penetrating with one piece after another.

When the maintenance is completed, the evaluation result for the trainee is shown in the text area, and it contains information on the evaluated mode (1—Automatic Mode, 2—Guided Mode, and 3—Exploratory Mode), the evaluated learning (1—replacement of superior-lid gasket and 2—replacement of inferior-lid gasket). Moreover, the evaluation result shows the percentage of correct answers during the maintenance procedures. In case the learning has been completed with no errors, the system makes available a button that enables the continuation to the next mode and a ‘‘restart’’ button for those cases where the trainee wants to repeat the task.

Exploratory Mode. When this mode is begun, the learner is already familiar with the assembly and disassembly procedures and, from this moment on, the trainee's knowledge is tested by performing tasks with no aid from the system. The trainee sequentially removes the screws, the press gasket, and the gasket and replaces them using the mouse. At the end of each correct step, the system shows a message in the virtual world indicating its accomplishment, which informs that the removal of the superior gasket has been concluded.

In the text area, no message is shown about the maintenance procedure; only the messages related to the correct or incorrect selection of pieces are shown. When the maintenance task in the exploratory mode is completed, the system informs that the learning has successfully concluded and, thereafter, the trainee is able to learn a new procedure, because he has passed all the learning modes related to the current procedure.

Operation Course

The operation course allows the trainee to visualize the HUE operation during a certain event as the electromechanical dynamics of the turbine-generator assemblage in the virtual world. This course is divided into two main parts: contingencies and startup procedure. In the contingencies, the HUE is interlinked with the power system and the operator can observe the behavior of the system during load variations and faults in the electrical system as short circuits. In the startup procedure of HUE, a virtual simulation is presented, in which the operator visualizes several requisite conditions necessary to turn off the HUE or interlink it to the power system.

Contingencies. The study of the dynamic behavior of a hydropower plant during contingencies is essential to the planning of expansion of an electrical power system. Without this knowledge, it is impossible to project the protection system for the generator and the grid and to plan the operation of the system, as described in the report by Kundur [15].

The main objective of this module is to contribute to the establishment of a relationship between the dynamic models of HUE operation with the VR environment, through visualization of the mechanical process of the turbine distributor.

In this module, it is possible to analyze the dynamic behavior of the turbine-generator assemblage in a HUE, operating in both the permanent and transitory states, which allows the visualization of a HUE linked to a power system and an animated vision of the operation of the hydropower plant.

By clicking on the ‘‘Turn button,’’ as shown in Figure 5a, HUE starts operation, detaching the animation of the rotating parts for the turbine-generator assemblage in the virtual world. The animation of the jointed parts of HUE is governed by the electromechanical dynamics of the turbine-generator assemblage

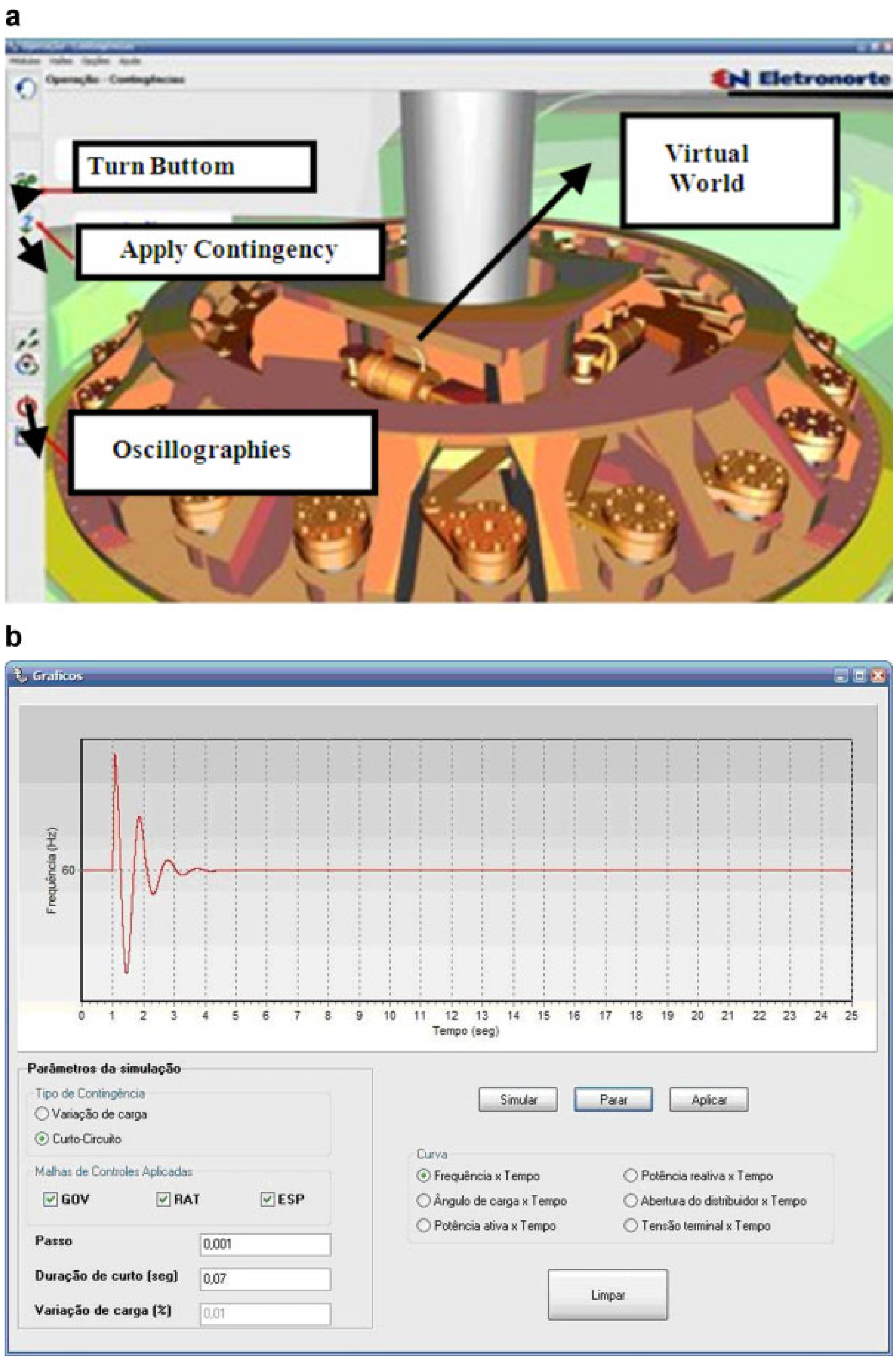

Figure 5 (a) Initial interface of the operation. (b) Graphs interface. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

and, according to the event simulated, a certain contingency can dynamically alter the values of the rotor speed as the mechanical torque, the opening of the distributor, and the terminal voltage, among others.

In the same sequence, by clicking on the "Apply Contingency" button, the application of a short-circuit is accomplished in the terminal of the HUE substation. By the application of this contingency, it is possible to verify the performance of the speed governor through the animation of the turbine-distributor system. For a Francis turbine, the control is exerted by an assemblage formed by the guide vane, servomotors, and regulation rings, collectively called the "distributor." Control is exercised by altering the position of the guide vane.

With the purpose of procuring a graphic visualization of the main electromechanical magnitudes of HUE during the operation, the Graphs interface (see Fig. 5b) has been developed. This interface is enabled by clicking on the Oscillographies button as shown in Figure 5a.

The visualization of the process of short-circuit in a hydraulic generator, obtained with the help of the VR environment, helps the professional to understand the phenomenon, which corresponds to the acceleration process of the generator and the consequence of this acceleration to both the turbine and the electrical system as a whole.

Figure 5b shows the behavior of the frequency of the turbine in a condition of short circuit. There is an acceleration of that and then the return to a steady condition. Such frequency is related with the speed of the generator rotor.

A single Francis turbine-generator, with the exciter and governor in a hydropower plant connected to the local load and infinite bus as shown in Figure 6a, is considered for the study. Although the actual power network is more complex, the single machine infinite bus system is, however, a useful starting point for a study of its design and performance [1,14,15].

The electromechanical simulation of the plant is implemented using the models suggested to the turbine, speed governor, and excitation system by Kundur [15], according to

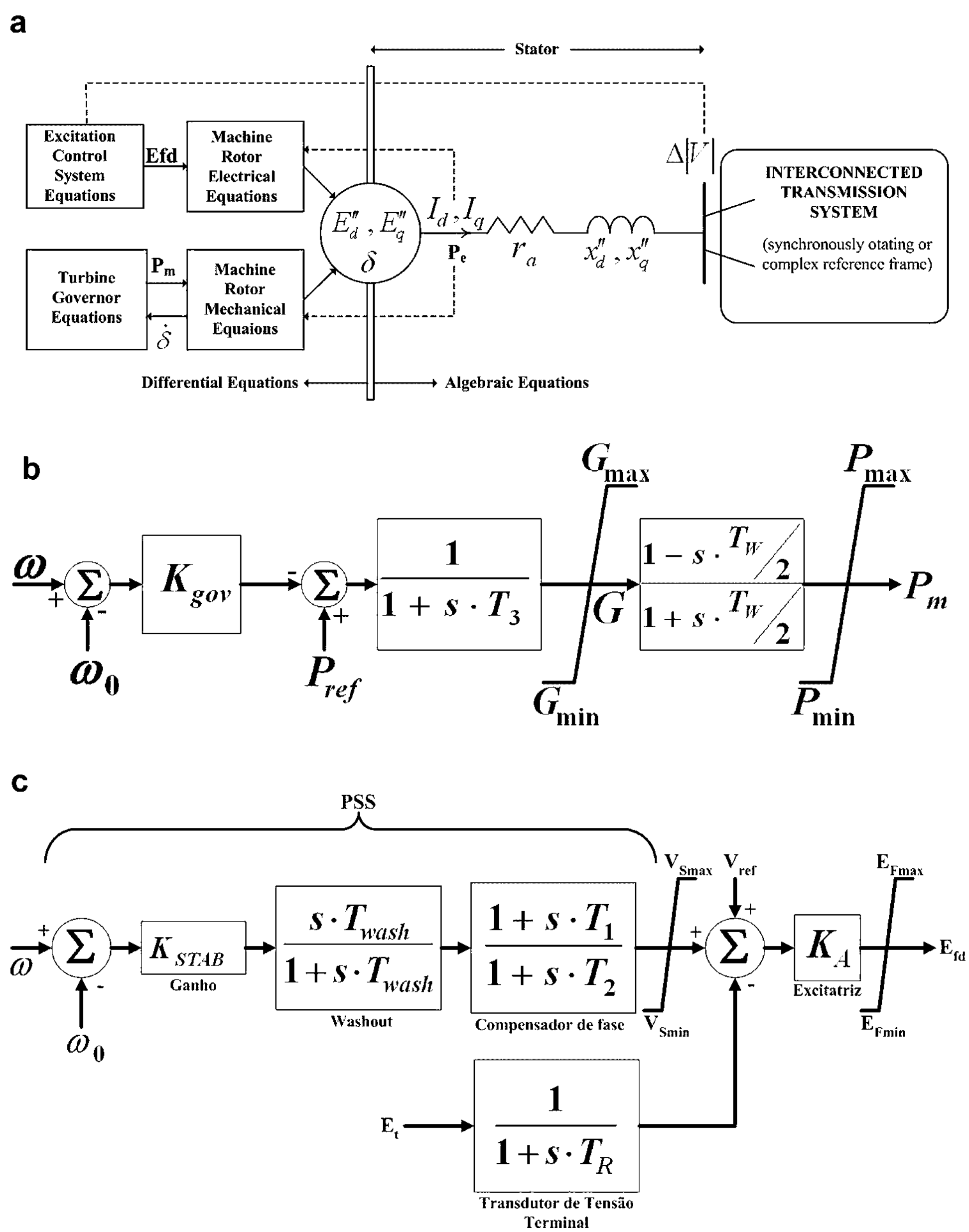

Figure 6 (a) A hydropower plant connected as SMIB system. (b) Speed Governor and Hydraulic Turbine Model. (c) Fast Static Exciter and Power System Stabilizer Model.

Figure 6b,c. The limits of the governors are determined such that the simulations become more realistic.

Startup Procedure. The knowledge of basic operations necessary for the startup, and restart procedures is tested in this course.

In this mode, a single start command causes a sequence of activities in which the necessary auxiliaries are started, and the necessary safety checks are carried out at each stage of the sequence. All through the startup and shutdown procedures, textual details are delivered to the user in the screen of the virtual environment.

In the startup Automatic Startup Procedure sequence, the machine is in the state of "Stopped Unit." After the startup command is given, the three-dimensional simulation of the startup commences, and a series of requisite conditions is verified automatically simultaneously: the open water-intake gate (see Fig. 7a), the closed distributor, and the lowered generator rotor.

In the Figure 7b,c, some of the requisite conditions of startup, necessary for the unit to be ready for the mechanical turn that causes the opening of the distributor are shown. This process begins the rotational movement of the machine, or in other words, the startup.

With the requisite conditions of mechanical turn being satisfied, the distributor is ready to open, and the machine enters into unloaded gear without excitation. At 80% of the rating speed, the requisite conditions for excitement are satisfied and the automatic closing of the field circuit takes place; subsequently, the unit enters into excited unloaded gear. With the requisite conditions for synchronization satisfied, the main circuit breaker is closed. At 90% of the rating speed, the unit is synchronized, it turns into unload and, soon after, it begins to take load.

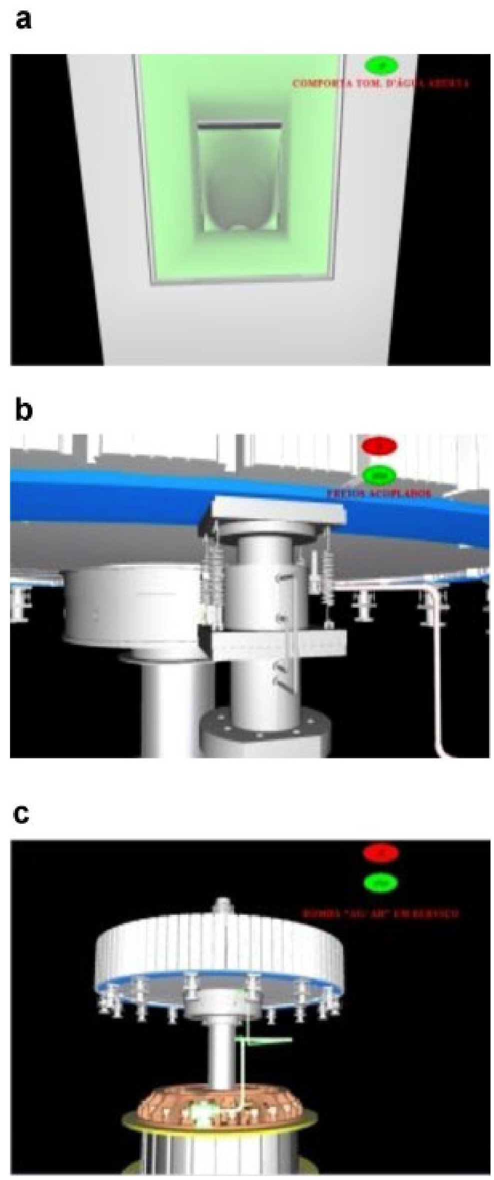

Figure 7 (a) Open water intake. (b) Coupled brakes. (c) Bomb turned on. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

SYSTEM EVALUATION

Many courses of electrical engineering can apply the principles of this manuscript, as energy conversion (I and II), electrical energy systems, and generation control. The visualization and animation techniques, initiated by the VR, help the students in clarifying the main steps of the energy-conversion process in a hydroelectric unit, wherein the hydraulic energy is converted to mechanical energy, and, finally, the mechanical energy is converted to electrical energy in the synchronous generator. The use of VR initiates an up gradation of the usage by the students, resulting in the improvement of the courses, and consequently, resulting in a better evaluation of these techniques.

In this sense, a case study is presented in this work, where it is taken into account the application of a questionnaire to the students of the third years of Electric Engineering, elaborated to evaluate the impressions of the users about the use of VGU. The questionnaire has objective criteria of evaluate aspects related to the interface quality provided by the system and the quality of the experience initiated by the learning. The interview process for the questionnaire, regarding the evaluation of the first system, has been conducted with a group of 52 students in the 7th semester of the course on electrical engineering at the Federal University of Pará, studying the subject Electrical Energy Systems (all students possess a theoretical knowledge of HUEs).

The process of evaluation relates many contents of the subject with the knowledge of the students from the bibliography and lecture notes adopted during the courses of graduation Engineering [1,14,15]. These subject contents include the construction of generators and turbines, the maintenance and operation of this type of system, their dynamic evaluation, regulator speed, the distributor, and other equipments of the hydraulic system.

The results of the questionnaire on evaluation represent the following perspective in percentage:

(a) Suitability of the system, as a whole, for the learning goals in the educative, maintenance, and operation of HUE is considered (see Fig. 8): 1—Unsuitable; 2—poorly suitable; 3—suitable; 4—highly suitable.
(b) The realistic quality of virtual pieces and equipments presented during the learning is considered: 1—unsat-

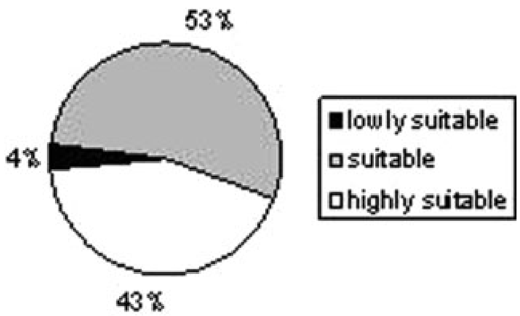

Figure 8 System suitability to the learning aims.

Figure 10 Interface learning level.

isfactory; 2—poorly satisfactory, in which a large part of the virtual pieces are not recognized in the real world; 3—satisfactory, in spite of some pieces presenting realistic limitations; 4—highly satisfactory (see Fig. 9).

(c) The system interface as a whole demands learning and an ability level. It is considered as: 1—difficult; 2—moderate; 3—easy (see Fig. 10).

(d) After learning, VGU system was concluded to provide the following: 1—did not add new knowledge; 2—offered only a general idea about the HUE components; 3—offered a general view of the HUE structures and an understanding of the spatial relation among pieces; 4—the contents in item 3 plus the logical understanding of sequences of equipment assembly and disassembly (see Fig. 11).

On the basis of the results, it is possible to say that the interviewed users consider the VGU system suitable for the learning goals. About the interface quality, a highly satisfactory realistic level of virtual pieces is reported to be offered. The learning level that is necessary for the user to understand the interface and search for solutions in new situations is considered to be between moderate to easy by the students. After the learning process, most of the people interviewed considered that the system (i) offered new knowledge about the main HUE structures and maintenance, (ii) presented in a suitable spatial relation between the pieces and equipments of HUE, and (iii) provided a deeper understanding of the assembly and maintenance operations.

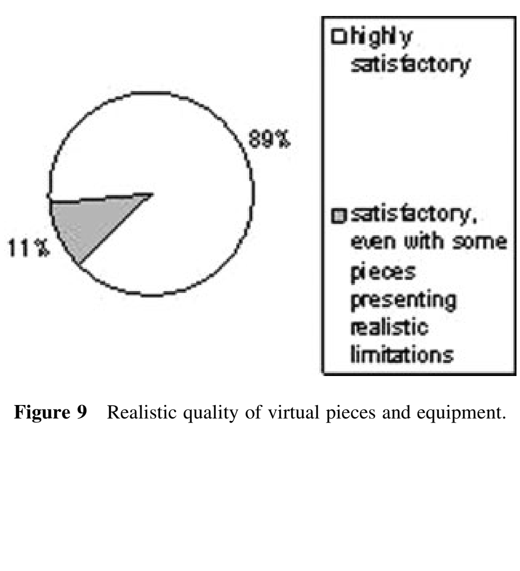

Figure 9 Realistic quality of virtual pieces and equipment.

The performance of the students in the case where the electrical energy system course adopted the learning based on VR was compared with the case from the previous semester, where that learning was not applied.

Initially consider the following correspondence between grades and concepts, adopted in the courses of the Electrical Engineering of the Federal University of Pará-Brasil: Grades Between 0 and 4.9 (Concept Insufficient); Grades Between 5 and 6.9 (Concept Regular); Grades Between 7 and 8.9 (Concept Good); Grades Between 9 and 10 (Concept Excellent).

In the semester, without the adoption of the learning based on VR, the performance of the students in the subject Electrical Energy Systems with respect to the grades and concepts is shown in Figure 12.

In the semester, with the adoption of the learning based on VR, the performance of the students in the subject Electrical Energy Systems with respect to the grades and concepts is shown in Figure 13.

It is important to consider that besides the fact that the learning on VR was introduced in the second semester, the teaching methodology applied in both semesters was the same in terms of the contents of the subject.

The results below clearly show the progression of learning by the students, confirming the statement previously described. It was possibly to verify the major interest of the students studying that subject, which motivates us to apply this process to the other subjects of graduation.

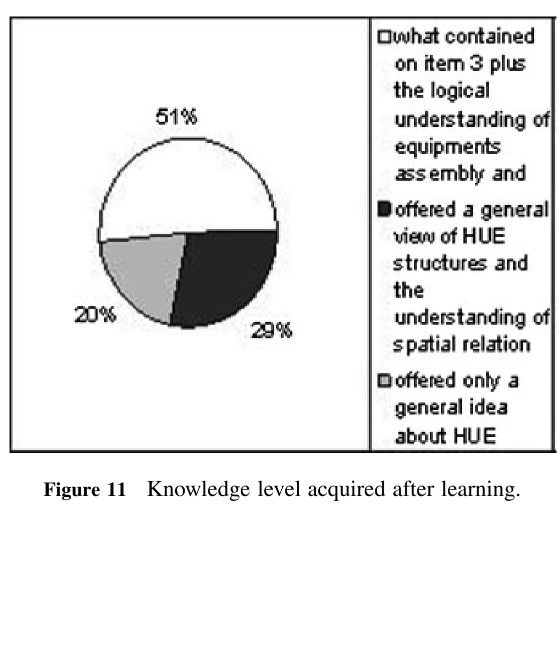

Figure 11 Knowledge level acquired after learning.

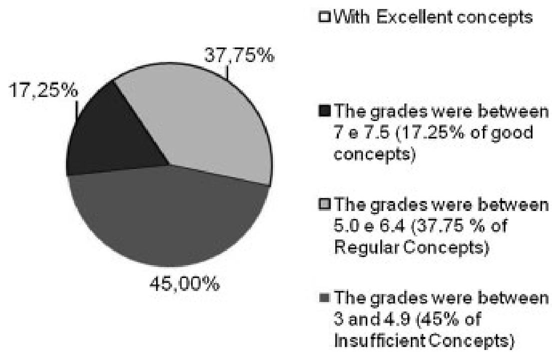

Figure 12 The grades and concepts without the adoption of the learning based on VR.

CONCLUSIONS

This paper presents the conception and the experimentation with the VR system, a project aimed at learning potential candidates through courses dedicated to the educative and maintenance of HUE pieces. The system adopts a new modular architecture, which makes it extensible and flexible, and allows a technician to create a technical instruction inside a virtual environment, called Virtual Technical Instruction, of operation or maintenance. This is a new contribution of this paper, as compared with previous workers.

The educative course offers an educational opportunity to students to know, in general, the main components of a HUE, and display internal details of each piece.

The operation course in this system, allows the trainee to virtually carry out the real-time operational procedures of the HUE utility. The maintenance course uses the learning approach based on practice and offers different levels of learning, divided into three modes: automatic, guided, and exploratory. These modes are accessed according to the acquired degree of knowledge of the trainee with reference to the maintenance and operational procedures. In this case, the combination of traditional evaluated learning programs with VR systems in the area of power system has been presented.

The application of virtual learning proposed by Angelov and Styczynski [2] offer specific modules for simulation of real situations, using Research Module, and for learning step-by-step to understand components of the power engineering, through the Teaching/Training Module, in single level of learning. The VGU works similarly to the previous system, however, offers different training levels, according to the acquired degree of learning by the trainee.

When compared with the VDSS solution, proposed by Guo et al. [3], the VGU tool offers a specific component for training and evaluation, in addition to the characteristics three-dimensional visualization. Considering the "help" properties of the virtual assembly process and disassembly simulation referred to in Sá and Zachmann's work [5], the VGU maintenance course has important features, such as training procedure involving the moving of virtual pieces based on real physics, in addition to containing collision-detection properties and an operation course.

The hydroelectric power plants use technical instructions to instruct maintainers and operators about the maintenance and operation procedures to be executed in their generating units. These instructions consist of well-defined scripts with 2D flat drawings and of activities in textual format. The available instructions of maintenance at the hydroelectric power plant are called Technical Instructions of Maintenance. Those consist of well-defined scripts with 2D drawings and activities in textual format. This material does not help too much the understanding of the technicians in charge for disassembly and assembly procedure of the equipments. The Technical Instructions of Operation also consist of texts written in paper and have the same problems as the Technical Instructions of Maintenance, therefore, it impels in the operators to understand about the effects on the equipments, propitiated by its direct action during a maneuver.

After evaluated by the students of engineering, the first version of the prototype developed here has been implemented in the hydroelectric power plant of Tucurui—ELETRONORTE (Concessionary of Electrical Energy of North Brazil) located in the state of Pará, in the north of Brazil, for presenting the software and providing initial training to electrical engineers and operators. Technical instructions of maintenance and operation have been tested in HUE by technical staff, and it has been unanimously accepted.

Of greater importance is the linking of the graphic output with the visualization of the dynamic response directly in the machine. It makes the learning quicker and easier to the student or other professionals of the electrical power systems, contributing to their development and gives them greater confidence about the procedures that are necessary to maintain a stable behavior of the hydro generator integrated to the electrical grid.

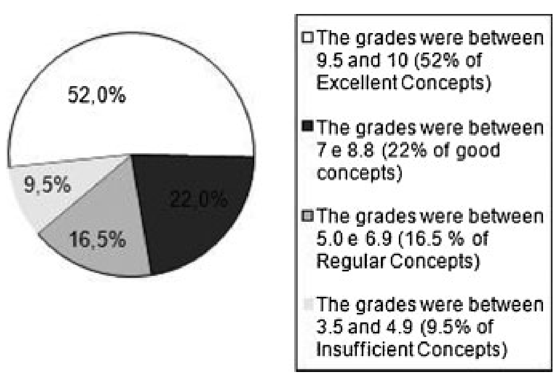

Figure 13 The grades and concepts with the adoption of the learning based on VR.

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