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Interactive Virtual Scanning Electron Microscope Inspired by 3D Game-Design

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Abstract: The scanning electron microscope (SEM) has evolved to become an indispensable tool for research and education in engineering, physics, nanotechnology, geosciences, materials science, biological sciences and other fields. However, training on a physical SEM is costly, time consuming, and often unavailable in economically disadvantaged areas. Advances in computer technology have made interactive three-dimensional (3D) virtual laboratory an effective tool for training in medicine and many engineering and technology fields. In the current work, in order to provide cost-effective hands-on training, a virtual 3D SEM was developed using the game development engine *Unity 3D*. It contains realistic 3D models of the physical components, created using *3ds Max*[®], a software for 3D modeling and rendering. The components are manipulated with scripts programmed using C# and JavaScript and then paired with the corresponding model. Users may view and operate the virtual instrument, save images for further analysis, and write a report. The developed virtual SEM was tested on diverse groups of users at multiple institutions, each divided to treatment and control groups. Feedback from these tests was collected and used for improvements in the overall quality of the simulated experience. In addition, users reported the experience of training on the virtual SEM as enjoyable.

Keywords: Scanning Electron Microscope (SEM), Simulation, Training, Computer Game, Virtual Reality

1. Introduction

The scanning electron microscope (SEM) is a vital research tool that provides topographical, chemical, and structural information in laboratory and industrial settings [1]. Training undergraduate and graduate science and engineering students in the use of the SEM is a key component in their academic preparation for their future career [2]. However, the SEM is expensive and delicate, which limits its availability to students and others. Another obstacle is its typically remote laboratory location, which makes some sort of distance education a necessity for

outreach to younger audiences and the general public. Advances in computer technology have made interactive three-dimensional (3D) simulation important for training in many fields, for example aerospace [3, 4], medicine [5] and education [6-11].

Today's generation of students grew up with computer games like *Nintendo* and the virtual reality social interaction experience *Second Life*. Hence, 3D virtual reality environments present an attractive, interactive, and effective way for young people to learn. They feel comfortable in cyberspace [12]. There are already some successful programs that take advantage of the video game approach to learning;

for example, the “virtual launch” simulation software developed by NASA [13]. In recent years, there have been several virtual SEMs developed [e.g., 14, 15]. They provide the users with a valuable online learning experience, explain the operation of the SEM, and demonstrate some types of images obtained using an SEM. However, they are not 3D or computer-game oriented. As a result, they do not simulate operation of the physical instrument. In our case, the interactive virtual 3D electron microscope simulates the physical instrument and provides the user with a hands-on experience, mimicking the operation of a physical instrument.

There were also some remote SEMs developed [16, 17]. These systems provide a virtual experience by connecting remotely with a physical SEM; their limitations include the need to mail the specimen to the remote laboratory, reserve available time on the instrument, and, in most cases, pay for time on the SEM. In addition, a remotely connected SEM needs a fast and reliable internet connection to operate. Our 3D virtual SEM can be used to provide cost-effective step-by-step hands-on training for students, without the need to use expensive and scarcely available beam time on the physical instrument. Other advantages include prevention of damage to an expensive instrument, accessibility for disabled students, and reaching out to economically disadvantaged regions in the US and around the world. The simulation is screen-based so the hardware requirement is minimal (Windows-based desktop or laptop), and the software resides on the hard drive so no internet connection is needed. The software is provided free to users in nonprofit organizations.

2. Methods

2.1. Project Goals

Our project goal was to develop an interactive virtual 3D SEM that adequately simulates the physical instrument. We first set out a plan for what was needed, used various commercial software programs to implement the plan, and then tested the final system for effectiveness. The principles that guided us in developing the 3D virtual SEM were the following:

The virtual instrument must mimic reality, and the learning environment in the simulation needs to create an experience similar to manually manipulating the equipment. This was accomplished by:

Creating an interactive 3D virtual SEM that looks similar to the real one so the user operates the simulated equipment in a manner similar to operating the physical instrument.

Incorporating real SEM images from physical experiments. During simulated experiments, the user saves and analyzes these images.

Emphasizing safe laboratory practices and radiation safety. No step in the simulation can be skipped, including the safety instructions.

Incorporating report writing as a requirement, especially

for undergraduate students. Reports can be graded with appropriate feedback.

The simulation must be able to run on low-cost equipment, such as any PC or laptop without special VR gear or internet connection.

The user should be able to train with no assistance. The virtual SEM simulation is launched from within a PowerPoint that provides both the necessary theoretical background, the physics behind the SEM, and contains embedded instructions and links to the virtual experiment. To assure that the simulation would appeal to millennials, an interdisciplinary group of students (graduate, undergraduate, and high-school) played an active role in the development.

2.2. Method of Virtualization

The virtual scanning electron microscope was developed using the *Unity 3D* game-design engine [18]. *Unity 3D* is most notably known for its professional use in developing various mobile and console games. The 3D environments created for the simulation were made by referencing physical laboratory equipment. The 3D modeling was accomplished through *3ds Max*[®], 3D modeling and rendering software [19], which incorporated the real-life dimensions of the SEM to create a proportionally accurate 3D model. Figure 1 shows the modeled electron column and sample chamber. *Adobe Photoshop* was used to add texture and finer details to the model. Much of the scripting in *Unity 3D* was done in *JavaScript* and/or *C#* and then paired with the corresponding model. An emulation of the SEM’s digital controls and viewing screen was created with standard web technologies (*JavaScript*, *Cascading Style Sheets*, and *HTML*).

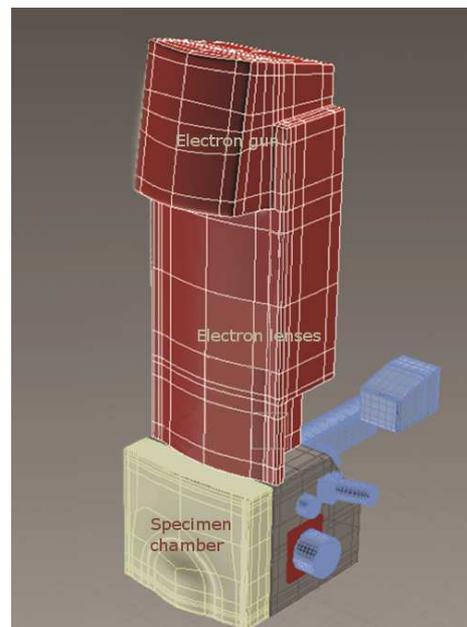


Figure 1. The simulated SEM column modeled with AutoDesk’s 3D Studio. The electron column consists of the electron gun, electron lenses, and scanning coils inside the final lens.

Operating the 3D virtual SEM. First, the user opens a PowerPoint containing a detailed explanation of the associated physical phenomena. The simulation is launched from within the presentation by clicking on the screen of the virtual computer that controls the SEM (Figure 2). The simulation is built to give the effect of the presence of a user in the laboratory. The user sees the instrument and operates it in a first-person view (FPV, a method used to control a device from the operator's viewpoint), adding to the authenticity of the simulation. In addition, the keyboard controls with W, A, S, & D keys combined with the mouse to look around the same as any first-person video game.

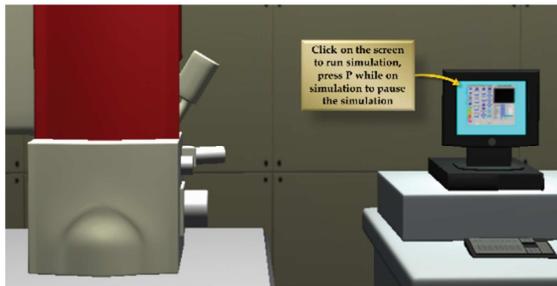


Figure 2. The interior of the SEM room with the SEM column and the control computer.

Before the “player” begins the game, he or she is required to view a slide show presentation, describing the theory behind the scanning electron microscope and the fundamentals of its operation, as well as the operation of the game, then take a test. Videos embedded in the presentation further illustrate important components of the instrument and their functions. The user is then prompted to start the game.

The user enters a virtual room with an environment consisting of an SEM column and a computer to control it. The scene is rendered to create the effect of the user seeing the room through the user's own eyes. The user navigates the environment with the arrow keys of the keyboard, whereas the viewing direction, pan and tilt, are controlled with the mouse. The mouse pointer resembles a hand and always remains in the center of the display. Actions, such as opening the SEM sample stage door are completed by clicking the mouse near the door latch (Figure 3).

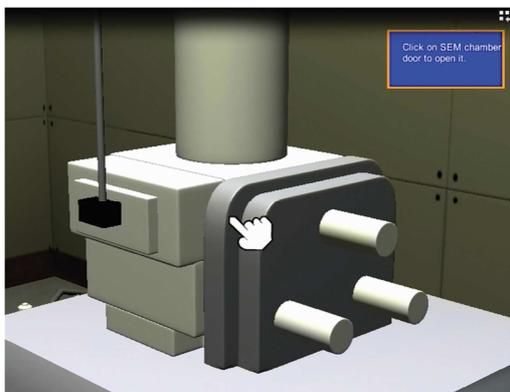


Figure 3. The mouse pointer, shaped as the user's hand. The user navigates the room by controlling his or her vertical and horizontal location.

To the right of the SEM is a cabinet with a variety of samples to choose from, each labeled with a text balloon. The user clicks on one to select it. This choice then dictates the necessary steps needed to prepare the material for proper viewing. In our simulation, electrically insulating materials must be sputter-coated with a thin metal film to reduce electrical charging (Figure 4), whereas conducting samples can be imaged without coating [1]. The sample is now brought back to the SEM. The sample chamber door is opened by clicking on it and the specimen is mounted on the stage; another click closes the SEM chamber door. From this point on, all activity centers around the computer screen that controls the SEM (Figure 5). A click on the screen opens the operating controls. To begin the session, the user evacuates the specimen chamber, turns on the high voltage, and carefully brings the filament current to saturation. The image brightness, contrast, focus, and astigmatism are then optimized. The screen in Figure 5 shows the effects on the SEM image of manipulating these controls.



Figure 4. Clicking on the sputter coater opens the lid. After the sample is selected, a click drops it into the sputter coater. When adequate vacuum is achieved, the coating starts.

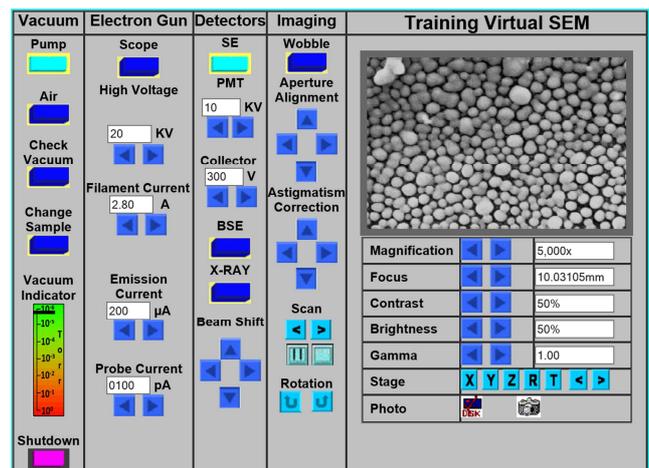


Figure 5. Controls for operating the SEM. On the screen is a secondary electron image of α -selenium balls (droplets) obtained by laser deposition from a solution. Particle sizes 1-2 μm .

The system responds interactively to commands for changes in accelerating voltage, focus, beam alignment, astigmatism, magnification, contrast, and brightness. The

results of the changes are observed immediately [20]. The optimized images may be saved for further analysis, documentation, and reporting. The raw data for the images in the virtual system must be previously captured by a real SEM and saved as collections of digital images. Switching between secondary electrons (SE) and backscattered electrons (BSE) is also done, using prepared images. The operation of the 3D virtual SEM is demonstrated at: <https://www.youtube.com/watch?v=sD5cXUYv2gU&feature=youtu.be>.

3. Results

To validate the usefulness of the simulated SEM and to obtain feedback for improvements, a series of learning modules were tested with undergraduate students at Western Michigan University, Kalamazoo, MI; Muskegon Community College, Muskegon, MI; and Instituto Federal do Maranhão (IFMA), Sao Luis, Brazil. These institutions were chosen to test the virtual SEM with student populations at a research university, a community college in an economically disadvantaged area, and an international institution. Comparisons of knowledge of SEM theory and operation were made among the groups of students that trained on the virtual SEM, students that trained using a physical SEM, and a third group that had only book or lecture learning with no hands-on training at all (physical or virtual). All three groups had learned about the scanning electron microscope as part of a materials science class. All students were given a multiple-choice test to assess SEM knowledge prior to conducting an SEM experiment in the laboratory and the same test again, immediately after submitting the lab report. Comparisons were made among the groups, as well as within certain groups (before and after the lab experience). Although the sample was small, assessment results from all three institutions, over several semesters, were consistent in demonstrating that the 3D virtual SEM was on par with the physical SEM in improving student learning. Also, both groups (virtual and physical SEMs) fared significantly better than the comparison group that performed no hands-on SEM training exercise at all. Furthermore, students who conducted the 3D virtual SEM lab expressed their interest in learning even more.

In addition, a software evaluation program was used to promote a continuous improvement feedback loop among 3D virtual SEM developers, SEM instructors, and pilot student users. External feedback was also obtained by providing the virtual SEM to instructors at numerous institutions around the US and in several other countries (on five continents). Lastly, a helpful critique was provided by lay people (with no science or engineering education) who were asked to run the simulation and provide input.

4. Discussion

The 3D virtual SEM was the last in a series of simulations we developed, mimicking materials testing instruments, such as, tensile test, cold rolling and heat treatment of brass,

concrete compression strength, and others. The choice of software to use (*3ds Max*® for modeling and rendering and Unity3D for virtual reality) was based on our accumulated experience. Compared to other virtual SEMs, such as MyScope™ [15], our system is rendered in 3D, which provides an experience that is closer to hands-on experience with a physical instrument. The user of our virtual SEM, operates it in a first-person view (FPV, a method used to control a device from the operator's viewpoint), adding to the authenticity of the simulation. In addition, unlike MyScope™, our software resides on the user's hard drive, requiring no internet connection. This was an important consideration in developing a virtual experience that can be used anywhere, including disadvantaged and rural areas. Planned future improvements include the addition of scale bar on the images, increasing the types of samples, and adding energy dispersive spectrometry (EDS).

5. Conclusion

An interactive simulation of the scanning electron microscope, inspired by 3D game-design, was developed to mimic the physical SEM and provide researchers and students with valuable hands-on experience for cost-effective training. The simulation is also helpful in providing the SEM experience to economically disadvantaged individuals and institutions, disabled persons, and members of the public. Assessment data indicate that the effectiveness of SEM training on the virtual 3D SEM was similar to that of a physical SEM.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors Contribution

PAG formulated the concept, prepared the instructional material, oversaw and guided the project development. IL developed parts of the virtual scanning microscope program and provided the samples' images. TWB imported the completed models and developed the virtual SEM software using Unity 3D. EAP assisted in coordinating student's laboratory experiments and helped to develop software for the virtual SEM. SH designed and added functionality to 3D models inside of Unity3D to replicate real life experiences. HJN created the instructional presentation and links to the program executable. PT helped coordinate the development and assessment activities.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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