Using Unity to Implement a Virtual Crash Site Investigation Laboratory in Support of Distance Learning Objectives

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ABSTRACT

The purpose of this paper is to describe the use of Unity to develop an interactive virtual environment to support distance learning in a higher education curriculum. Online and distance learning has become a viable delivery method for course content in higher education and is continuing to gain acceptance and popularity as students and faculty become more comfortable with this medium. The demand for online learning and the emerging requirement to have students bring their own devices to the classroom is also driving a need for innovative methods of instruction. This paper discusses the need to utilize a virtual crash site for the Embry Riddle Aeronautical University (ERAU) – Worldwide Master's-level Crash Site Investigation course and the decision to utilize the Unity gaming engine for its implementation. Many obstacles had to be overcome during the development and implementation of the virtual laboratory environment to ensure that it provided an effective learning environment for students, and that it is engaging, useful, and intuitive enough for students who are not "gamers." A set of course objectives was provided by staff members of the College of Aeronautics from the school's eLearning sector. These objectives were then transformed into a concrete set of requirements to be used as the basis of development. Derived requirements were developed to define how to meet these objectives in the virtual world. This paper will address why Unity was chosen for the development environment; it will discuss the different capabilities of the lab desired to meet the course objectives (including tasks like taking photographs and measurements, diagramming the crash site, and interviewing witnesses); and how the course is being made available to students.

The Virtual Crash Site Investigation Laboratory is currently in its pilot course; therefore, data showing the effectiveness of the course is not available. However, feedback from staff and technology personnel has been positive. Once the course is complete, student surveys and instructor feedback will be collected to determine the aspects of the class that were well received, as well as any issues that need to be addressed.

ABOUT THE AUTHORS

Christina "Tina" Tucker has ten years of experience in aviation simulation and training. She began her career as a software engineer, with most of her experience in C++ and C#, but has recently transitioned to the program management field. She has two years of program management experience, including the development of the virtual laboratory discussed in this paper. Tina has worked on a variety of training devices, from desktop training to full flight simulators.

Jimmy Moore a Certified Modeling and Simulation Professional, is co-founder and Vice President of Pinnacle Solutions, Inc. and has more than 20 years of experience in simulation and modeling of aircraft and missile systems for distributed, man-in-the-loop, and training applications. He has worked on various programs in support of Department of Defense (DoD) and commercial customers. Specific experience includes the development of high fidelity flight training devices, development of engineering and analysis cockpits for Pilot Vehicle Interface (PVI) analyses, Synthetic Environment development, simulations to support Science, Technology, Engineering and Math (STEM) programs and design and execution of distributed simulation exercises.

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INTRODUCTION

Embry-Riddle Aeronautical University (ERAU) offers unique programs in aviation and aerospace with residential "brick and mortar" campuses in Prescott, AZ and Daytona Beach, FL. ERAU-Worldwide is the distance learning segment of ERAU supporting more than 150 on-site locations around the world, as well as purely online education for students. One of the courses offered is a Master's-level Crash Site Investigator Course, which includes a laboratory component. At the Prescott campus, students have access to the Robertson Aircraft Accident Investigation Laboratory (RAAIL), providing crash-damaged aircraft that are used by students in the Safety curriculum.

Figure 1 - ERAU's Robinson Aircraft Accident Investigation Laboratory (RAAIL). This 8-acre facility gives students the opportunity to conduct simulated hands-on field investigations of a variety of aircraft accident sites. The area features nine fully recreated field scenario settings, two partial accident recreations, and natural areas where faculty members can stage additional crash site simulations (Prescott.ERAU.edu).

With such a unique and beneficial resource for its residential students, the school determined virtual lab environments were needed to expand the educational opportunities for their distance learning students. The goal was to bring laboratory environments, that have historically been limited to a physical form, into a virtual environment in a very realistic way; ultimately providing a real-life, hands on experience for students from anywhere in the world. Specifically, the Virtual Crash Site Investigation Laboratory was used as a proof of concept program to determine the effectiveness of the laboratories and how best to implement and deliver them to students. As technology-enhanced learning platforms and digitized content continue to evolve in both popularity and ability, a virtual laboratory that can be used across academic disciplines and delivery modes (classroom, online asynchronously, online synchronously, or blended modes) is desired to support next level learning opportunities.

MEETING COURSE OBJECTIVES

Course objectives for the physical Crash Site Investigation Laboratory were used as a starting point for development of the virtual laboratory. These objectives were refined as development of the virtual lab progressed. In order to develop the most comprehensive course objectives and meet these objectives appropriately using online technology, the school's staff was heavily involved with design decisions. The following course objectives were provided prior to development:

- Explain and apply the composition and role of the initial response or "go team"

- Identify and demonstrate through analysis the methods, techniques, and procedures involved in aircraft accident investigation
  - Aircraft Systems
  - Aircraft Structures
  - Power Plants
  - Human Factors
  - Operations
- Demonstrate the methods of collecting, preserving, and reconstructing accident scene data
- Understand the major elements of accident scene photography
- Demonstrate witness interview techniques
- Understand and apply investigative techniques associated with the three phases of crash survival (impact, egress, and environment)

Once the program was underway, there were many design decisions that had to be addressed to develop the laboratory so that it meets the needs of the students while also keeping them engaged throughout the course. Three major questions needed to be answered prior to development:

1. What tools should be developed within the virtual world to ensure it meets the same required course objectives as the physical laboratories?
2. What development environment will provide the best student interaction, while also meeting the requirements of the class regarding assignment submission, day-to-day instruction, etc.?
3. How will the laboratory interface with the school's Learning Management System (LMS)?

The Crash Investigation Laboratory Application

The Crash Investigation Laboratory contains nine modules; six of which include lab activities.

Module Number	Module Description	Lab Activity
1	Legislation, Regulation, Roles and Responsibilities	None
2	The Investigative Process, Accident Reports and Introduction to the Virtual Crash Lab	Students view the animated crash video and take the laboratory virtual tour
3	Data Collection and Database Part I	Students reconstruct the accident site using the Grid Map and other evidence collection tools
4	Data and Data Collection Part II	Students interview one informed witness and one uninformed witness
5	Human Factors Investigation	None
6	Structural and Fire Investigations	Students examine the non-damaged Boeing 737 model and collect evidence of structural deformation and degradation
7	Aircraft Systems Investigations	Students view fuel and electrical system cutaways and determine potential sources/causes of system failures
8	Survival Factors and Crashworthiness	Students photograph and explain 10 items that could have influenced survivability associated with impact, egress, and environment
9	Operations and Maintenance	None

Table 1 - Virtual Crash Lab Modules and Laboratory Activities

The virtual crash laboratory uses gaming engine technology to reenact an actual aviation incident and simulate the subsequent crash site. The virtual crash laboratory immerses students in the scenario without the requirement to travel to the Prescott RAAIL facility. The laboratory allows students to collaboratively maneuver through the crash site while performing tasks commonly conducted by an investigator in accordance with the pre-determined course curriculum. Students are introduced to the scenario through a pre-rendered introductory video based on actual NTSB data.

Figure 2 – Introductory Crash Scene. The Introduction to the Crash Scene Investigation Laboratory Provides an Accurate Depiction of an Actual Incident Based on Cockpit Voice Recordings and Black Box Data.

The Virtual Crash Site Investigation Laboratory is deployable to Windows, Android, and Mac operating systems and is available for desktops, laptops, tablets and mobile devices, allowing students to access the laboratory from anywhere around the world with a connection to the internet. Once downloaded, the application is not dependent on an internet connection, providing further flexibility for students. Some of the key capabilities include the ability to customize players, examine evidence more closely in a virtual hangar, capture pictures of evidence, view actual crash site photos, display grid lines for investigation, and measure between pieces of evidence and interview witnesses, all via an application launched from the school's Learning Management System or a mobile app store.

The Crash Site

Due to the complexities of developing a crash scene from scratch, and to ensure training realism, it was decided that historical data should be used in developing the scene. This particular crash was modeled after an actual incident that took place in Little Rock, AK in the 1990s. The school's Subject Matter Experts (SMEs) provided the National Transportation Safety Board (NTSB) report, including crash photos and interview transcripts, to make the scene and investigation as realistic as possible. Photographs were used to ensure the components were modeled to scale so that measurements taken during the training modules would be accurate. The interior and exterior of the plane were modeled down to details specified by the crash investigation SMEs to ensure realism during evidence collection. Seat belts, for instance, had to show failures in three different modes – shear, tear, and failure.

Figure 3 – Virtual vs. Real Exterior and Interior Views. The Virtual Laboratory Scene Elements Were Developed to Replicate the Actual Crash Scene as Closely as Possible.

Students can maneuver through the crash site in first or third-person view using keyboard or touchscreen (mobile devices) controls. While examining the exterior of the aircraft, students can "walk" freely on their chosen path around the aircraft. However, if a student wishes into enter the interior of the aircraft, he or she must don their hazardous materials suit before proceeding. Once inside the plane, the student is always in first-person mode and is on a predetermined track progressing through the aisle using his or her forward and back keys or single touches on a mobile device. During development, engineers determined that, due to the amount of debris inside the plane, students would become stuck too easily if they were able to maneuver freely; therefore the track was developed to allow ease of movement inside the plane. Students can enter the front of the plane and see damage to the cabin from crash impact, or they can enter the rear section of the plane and see the damage from post-crash fire. In this crash, for example, all fatalities occurred in the rear section of plane. The majority of these fatalities were due to a post-crash fire that developed during a delay in emergency response to the accident.

TOOLS

Evidence Collection

Evidence collection is one of the major components of crash site investigation. In order to determine the cause of the crash, investigators must take photographs of different aspects of the crash scene, review human factors, take measurements, document location of fatalities and survivors, and recreate a small scale view of the post-crash scene. In actual crash site investigation, these tasks are accomplished by using the "Go Bag." In the laboratory, students are provided a virtual Go Bag with tools that would be used on deployment to an actual crash scene. Students can use the tools provided in the Go Bag to complete assignments related to the course work they are studying, for the specific module they are completing (e.g. measuring and diagramming the crash scene, taking photographs of elements in the crash scene, and examining components of the aircraft to determine the cause of the crash.)

Due to the natural limitations of any virtual environment, development had to be approached with the mindset of making tasks a realistic as possible, while being cautious not to introduce investigation techniques that might result in negative habit transfer to actions taken in an actual crash site investigation. Students need to learn the appropriate sequence of an investigation, as well as learn the correct steps to take for each of the investigation tasks. Modeling a real crash with a great deal of historical data, and a complete NTSB report for reference, allowed developers to include small, highly informative, but sometimes overlooked evidence points that students need to ensure they examine at any crash site (i.e. seat belt failures, signs of material fatigue, and other equipment failures). Some of the key features of the virtual lab environment intended to aid the student in developing a complete accident report and determining the cause of the crash include the capability to:

- "Pick-up" pieces of evidence and examine them in the evidence viewer
- Capture pictures of evidence and/or scenery to be stored for later use
- View actual crash site photographs
- Layout gridlines using the Go Bag Grid Tool
- Measure between two points using the Go Bag Tape Measure
- Interview witnesses

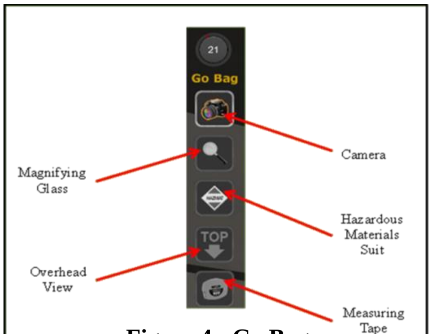

Figure 4 - Go Bag

Examination Hangar

A main component of crash site investigation is to determine what equipment, if any, might have failed and contributed to the cause of the crash, as well as what equipment could perform better to reduce injuries and fatalities to passengers. In order to accomplish this task, items need to be thoroughly examined to see what structural damage or deformities are present. Throughout the crash scene, multiple high-importance items, as identified by SMEs, are shown with a red magnifying glass floating above them. This icon indicates that it can be taken into the hangar to be examined further. The component is selected by simply clicking on the items using a mouse, or tapping the item in any of the touchscreen, mobile applications.

Figure 5 - Magnifying Glass Icons. The Magnifying Glass Icons Provide Visual Cues to the Students for Which Scene Elements are Available for Further Inspection in a Virtual Hangar.

Often during an investigation, items are taken to a hangar or warehouse for review at a later date. This virtual examination hangar allows students the opportunity to take a closer look without waiting several days before the item has been moved and is ready to be examined. When the student selects a component in the laboratory, it is immediately taken into the virtual evidence hangar. The evidence hangar allows the student to examine evidence more closely regarding deformation, distance between damage points, faulty components, etc. Students can rotate and zoom in on components to see the extent of damage. They can take notes regarding the damage to the selected component and identify any deformities they believe might have caused the component to work insufficiently. Students can also view real photographs of the component, which provides them with a means of viewing what the component should look like normally, before the accident occurs. It provides details that would typically have to be researched by an investigator while they were in the hangar. All of the data recorded by the student can then be exported for inclusion in the student's final report to be turned in at the end of the semester.

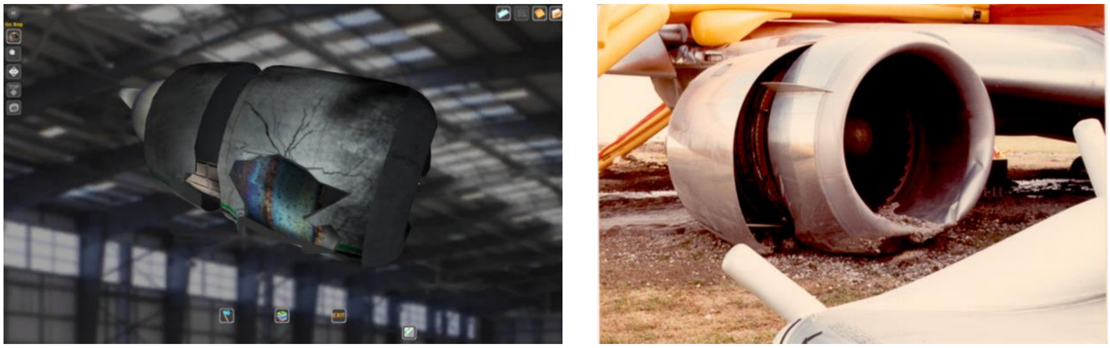

Figure 6 - Examination Hanger. The Examination Hangar Allows Students to Rotate the Items in 3D Space and Zoom in for Closer Inspection and Evidence Collection.

Camera

During an actual crash site investigation, thousands of photographs are taken to document debris and its location, structural damage to the aircraft, ground scarring, body markers of fatalities, seat locations of survivors, etc. In the virtual laboratory, students need the ability to take photos and document any findings associated to the photograph. The camera tool developed allows students to zoom in and out on the desired location and take a photograph. They are then able to open their virtual notepads and document any pertinent information related to the photograph. Finally, the photograph, along with any notes, can be exported for the final report developed by the students.

Figure 7 - Camera View. Indicated by the 5 Focus Boxes, the Camera View Allows Students to Capture Images for Use in their Final Laboratory Report.

Tape Measure

Measuring between two pieces of evidence, as well as measuring the size of the damage to a single component, are very common tasks accomplished during a crash site investigation. One of the most challenging tasks during development of the laboratory was creating an intuitive and effective method for measuring between two points. Multiple methods for measuring were tested, including measuring in 3D space, but the driving factor became ease-of-use on all devices. Ultimately, requiring the student click the start point and end point of the desired measurement was determined to be the most effective for mobile devices, therefore it was the sole measurement tool developed; keeping the capabilities available for each of the device types the same. As with any notes associated with photographs, measurements can be added to the virtual notebook for future reference and inclusion in an accident report.

Figure 8 - Using Tape Measure. A Particularly Challenging Application is the Measuring Tape Tool that Allows Students to Collect Data on Debris Dispersion and Determine Locations of Evidence.

Grid Map

The grid map is used to enable students to "map" the crash site and post-crash aircraft components location from overhead for reference after they leave the crash scene. In actual crash site investigation, NTSB team members use graph paper to recreate the crash on a smaller scale and get a better overall picture of the extent and expansiveness of the crash. The grid view allows the students to replicate this behavior within the virtual laboratory. The student can rotate the view, as well as zoom in and out using the grid map to get more detail as needed. The grid lines are to-scale in reference to aircraft component sizes. The student can also switch between the grid view (overhead) and the first/third person view as necessary.

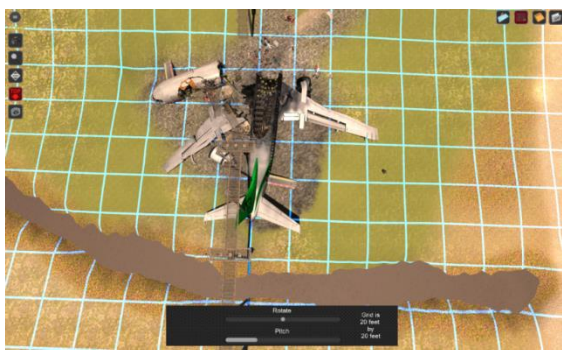

Figure 9 - Grid Tool. The Gridding Tool is a Common Technique Used in Forensic Analysis to Determine and Record Evidence Locations in Relation to the Surrounding Area.

Witness Interviews

Many different techniques are involved in witness interviews due to the different types of witnesses that can be involved. For instance, an informed witness or someone with flight experience is interviewed much differently than an uninformed witness. An informed witness will receive a certain type of questions given their background. In addition, the informed witness's mood and reactions will more than likely be different from that of an uninformed witness. An uninformed witness or a passenger with no flight background may become very stressed during the interview session and may not understand the difference between standard flight procedures and what went wrong during the particular incident. Each type of witnesses' answers can vary greatly during their interview. Due to all of these variables, a response tree was developed to provide different answers to different students, as well as different answers each time the same student progresses through the interview. The possible responses range from truthful to outright lies. Even with the actual transcripts from the NTSB report, this tree was possible because of the range of questions asked and the varying responses based on the witness's mood and reaction to other questions. The option of text-to-speech and use of student-developed questions was explored during early development. The text-to-speech option was not exercised due to its cost of development and implementation. It was also determined that allowing students to ask their own questions could be a potential distraction to learning. For example, students could make up off-the-wall questions that did not pertain to the coursework. Again, implementation of a system that would allow open questions, but limit responses to valid questions, was determined to be too costly. Finally, after discussing options with the school's staff, the "canned" response tree was determined to be the most beneficial.

Figure 10 - Witness Interview Module. The Witness Interview Module Provides a Menu Driven Selection of Questions and Appropriate Responses Based on Actual Eyewitness Accounts of the Incident.

DEVELOPMENT ENVIRONMENT

While multiple game engines were examined prior to contract award, Unity was ultimately chosen as the development environment. Two independent analyses were performed – one by the school and one by the developers. In both scenarios, Unity was chosen as the development environment of choice. From a development perspective, Unity has many benefits. There are numerous models available in public domains and Artificial Intelligence (AI) and physics models can be easily imported. In addition, terrain generation is very user friendly. Unity's flexibility and ease of use, along with price, were the other major contributing factors. Some of the school's directed factors that were taken into consideration are discussed below.

Multiple Operating Systems

One of the requirements of the virtual laboratory is that it must be compatible with multiple operating systems. Students enrolled in the eLearning curriculum needed to be able to use the laboratory on Windows PC, Apple iOS, and also via web-player. Students enrolled in the course are not only geographically dispersed, but are also in many different scenarios academically. One of the major groups that had to be taken into consideration was deployed military. Service members deployed to different areas may not have consistent, reliable internet service. The approach to this challenge was to create the laboratory where it could be downloaded to a PC, Mac, or mobile device. Once downloaded, the student can complete the necessary exercises and export any data recorded. Then, when the student has internet access again, he or she can email a report to the professor. Finally, applications developed using Unity can be distributed freely and there is no need for the user to have any special software (Craighead, 3). As development progressed, engineers did find that the web-player application ran much more efficiently using Google Chrome.

Device Types

Another requirement set by the school was that the laboratory must work on multiple devices. From standard desktop PCs to smart phones, the laboratory must meet the same objectives and provide the student with an effective means of learning. Due to these requirements and the need to minimize development costs by reusing as much software code as possible between the device types, some of the graphics were developed with a lower pixel count to allow the modules to easily transfer between devices and not hinder performance. The PC version of the laboratory is accessed through the Blackboard Learning Management System. Mobile versions of the laboratory were developed for both Apple's App Store and Android's Google Play Store. For mobile devices, the apps can be downloaded by any user, including those who are not students at the school. After the app is downloaded, however, the user must have an access code that is provided by the professor and is only valid during the length of the course. These access codes are refreshed for each session.

Compatibility

Compatibility with current student technology was also something that had to be taken into consideration when choosing a development environment and how to deploy the laboratory. Many 3D gaming engines require substantial processing power to be able to run graphics intensive environments. In addition, to get the highest quality graphics, high-end graphics cards are often required. The school did not want to require their students to replace their current devices to have access the laboratory, therefore the eLearning existing minimum technology requirements were used for the virtual laboratory minimum requirements as well.

LEARNING MANAGEMENT SYSTEM (LMS) INTERFACE

Module Access

Students access modules via Blackboard, the school's Learning Management System (LMS). The virtual laboratory includes three major components. First, the introduction scene, an animation video of the aircraft approach and crash, is viewed during the second module of the class. The witness interviews were also considered a separate entity, as they took place in a different environment. These interviews are accessed during the sixth module. Finally, the crash scene itself was an entity in itself. While one crash scene was developed, multiple instances of the scene were created to reduce the size of download for mobile students. Each of these instances was then posted in the appropriate module's folder. The individual instances gave the student unique visibility into different sections of the crash scene, while "locking" certain areas of the crash. For instance, during module three when the student gets their first real glimpse into the crash scene, the interior of the plane is locked so the student cannot enter. This approach was used to keep the student interested in the scene, rather than letting them view the entire scene the first week and lose the newness of each section of the crash.

Assignment Submission

Assignment submission was another challenge that developers faced. While Unity is a very powerful tool with regards to 3D gaming engines, it did not support data formatting adequately. After discussing assignment submission options with the staff, it was determined that it would be accomplished separate from the laboratory. As mentioned previously, the final assignment for this course is a crash site investigation report encompassing notes, photographs, interviews, and any other data collected during the investigation. Unity is able to export all of the information documented during the course into HTML format. After the export, students are then able to format their own data into a concise report that meets the requirements of the course and demonstrates proficiency. It should be noted, however, that during the trial course, students struggled with the formatting process and a Word-based export is currently being investigated.

Course Effectiveness

The Virtual Crash Site Investigation Laboratory is currently in its pilot course; therefore, data showing the effectiveness of the course is not available. However, feedback from staff and technology personnel has been positive. Once the course is complete, student surveys and instructor feedback will be collected to determine the aspects of the class that were well received, as well as any issues that need to be addressed.

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