An Interactive Virtual Environment for Teaching "Triangulations and Coordinates Calculations" to Surveying Students

Hazar Dib
Department of Building Construction Management
Purdue University
West Lafayette, IN, USA
hdib@purdue.edu

Nicoletta Adamo-Villani
Department of Computer Graphics Technology
Purdue University
West Lafayette, IN, USA
nadamovi@purdue.edu

Stephen Garver
Department of Computer Graphics Technology
Purdue University
West Lafayette, IN, USA
sgarver@purdue.edu

***Abstract*—This paper presents ongoing research aimed at improving surveying education through the use of virtual environments. Teaching surveying presents several challenges such as low student competence in mathematics, geometry and trigonometry, limited student access to instruments, limited availability of terrains on which to practice, dependency on weather conditions, and more. Prior research suggests that surveying education can be significantly improved with the use of digital teaching aids and virtual instruments. The goal of the work reported in the paper is to enhance traditional surveying instruction methods with a unique approach: an interactive Virtual Learning Environment (VLE) that supports students' mathematical representational fluency and includes realistic virtual terrains and surveying instruments that look, operate, and produce results comparable to the physical ones. The VLE is aimed at undergraduate students enrolled in Civil Engineering, Architecture and Building Construction Management programs and includes 5 educational modules; in this paper we describe the design, development and initial evaluation of the "Triangulations and Coordinates Calculations" module.**

Keywords- Virtual Learning Environments; Surveying Education; Usability Evaluation

I. INTRODUCTION

The objective of the work reported in the paper was to develop and validate the usability and functionality of one of the 5 modules of the VELS [1; 2; 3]. The VELS (Virtual Environment for Learning Surveying) is a virtual environment for teaching/learning surveying concepts and practices. It includes five educational modules that are specifically designed to address key theoretical and practical challenges the students face in traditional surveying courses: (1) Basic Surveying math; (2) Chaining; (3) Differential Leveling; (4) Triangulations and Coordinates Calculations; (5) Current technologies in surveying. The paper describes module 4 which focuses on proper techniques and the math skills needed in order to calculate horizontal angles and vertical angles, find a meridian/ reference line, find the correct orientation and directions concepts of Azimuth and Bearings, calculate the coordinates based on bearings and distances, perform traverse calculations, compute angular errors, determine closure error, distribute error for closure and balance the angles and distance.

Teaching triangulations and coordinate calculations, which are some of the most important topics in surveying courses, presents several challenges. In general, during lecture the students are able to understand the math/geometry concepts if the axes of reference are drawn on the board. When the axes of reference are non existent (e.g. in the case of the field exercise), many students are not able to visualize these concepts and therefore cannot successfully apply them in a real world scenario. This is due to the fact that many students lack representational fluency in mathematics, e.g., the ability to reason with and among multiple representations.

In addition, when performing exercises in the field, students work in teams and therefore it is difficult for the instructor to accurately assess the performance of each individual student; the ability to practice in the field is greatly affected by weather and lighting conditions; the number of terrains on which to practice is usually limited to the terrains that are available on the university campus; the students' ability to repeat assignments and further practice with the equipment is limited by the availability of the instruments, and team members.

The VLE module described in the paper overcomes many of these limitations. It has the potential to improve students' representational fluency in math by exposing them to multiple interconnected representations (i.e. concrete, numeric/symbolic, textual, pictorial, real-world representations) of mathematics, geometry and trigonometry concepts in the context of surveying. It provides students with an opportunity to practice the concepts and procedures of leveling independently from team members; it allows students to practice regardless of weather or lighting conditions; it gives them the opportunity to perform assignments in a variety of virtual terrains thus breaking the monotony of redoing the same exercise in the limited available space; it enables the students to repeat the assignments as many times as they need. The VLE module includes realistic terrains and instruments that look, operate and produce results comparable to the physical ones. Furthermore, it is true to traditional surveying practices, as it

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requires the students to perform the same essential steps that are involved in a traverse exercise in the field.

The VLE is being created using an iterative user-centered development approach that includes two forms of evaluation: formative and summative. In this paper we describe the design and development of the software tool and report the findings of an initial formative evaluation with a panel of experts. The paper is organized as follows: in section 2 we discuss current challenges in surveying education; in section 3 we discuss the benefits of virtual learning environments (VLE) and report prior work on VLEs for engineering and surveying education. In section 4 we describe the VLE module and its technical implementation and in section 5 we report the findings of the expert-panel evaluation. Conclusion and future work are included in section 5.

II. Surveying Education

Surveying is a core course in the Civil Engineering, Building Construction Management, Geomatics, Geography, Agriculture and Forestry, and Landscape Architecture curricula. Surveying is the science of studying the 3D shapes of the earth's curvature and surveying concepts are founded in geometry and vectors principles. In the context of construction layout, angles, distances and elevations are used to set up the building footprint at the correct location, establish level elevations and plumb vertical surfaces.

Traditionally, a surveying course includes three components: (1) the theoretical foundation of surveying, which includes math, trigonometry, geometry and physics concepts (often instructors teach fundamental concepts of surveying using examples from textbooks and illustrations on the chalkboard); (2) instructor demonstration of functionality and manipulation of real surveying instruments; and (3) student practice (in groups) with real instruments. This traditional way of teaching construction surveying presents several challenges.

One major problem in teaching surveying is what R. Elgin calls "The Demise of Basic Surveying Mathematics" [4]. Elgin reports "..a distinct decline in the math skills of students taking surveying courses…", and a decline in the students' ability to transfer these concepts into practice in the context of surveying.

Another challenge in teaching surveying is that "…many surveying instruments are required and the cost of purchasing and maintaining the instruments can be very high. The effectiveness of the lesson can be influenced by the weather, location and time of day; and as many operations involve fine actions, the instructors often face the difficulty of clearly demonstrating each step to every student in the field" [1]. One of the authors has taught the surveying course over 30 times and has observed over 750 students; below is a summary of key students' feedback on the surveying class. Most students believe they would enhance their learning of surveying and construction layout concepts and practices if they were provided with:

- One to one mentoring and guidance in the learning process
- Additional time to practice with the equipment
- Less dependency on team members
- Immediate feedback on accuracy of measurement
- Access to standardized equipment (for instance, steel tapes available at most facilities are seldom standardized. As a result, it is very common that students who follow all steps and procedures accurately are not able to achieve accurate results and thus, get frustrated and discouraged).

From the instructor's perspective, another challenge is the need to accurately document the individual student performance in settings where the nature of the exercises requires collaboration between at least two students. It is difficult to evaluate an individual student's performance, as it only takes one student to make a mistake in order for the team to get the wrong measurement. It is not uncommon for good students to get penalized for the mistake of another team-mate.

Students who rely on distance learning or are enrolled in programs at smaller/satellite campuses (these smaller campuses usually cannot afford to buy the surveying equipment) are currently deprived of opportunities to practice with the instruments and have to make several trips to the main campus during the semester in order to learn best surveying practices or do without.

III. Virtual Environments and Learning

An Interactive Virtual Learning Environment (VLE) is defined as a designed information space in which the information is explicitly represented, educational interactions occur, and students are not only active, but actors, i.e., they co-construct the information space [5]. The pedagogical benefits of interactive virtual learning environments have been examined (and are currently being examined) by researchers in the areas of computer graphics, cognitive psychology, visual cognition, and educational psychology. In general, research findings show that virtual learning environments can be more effective than traditional teaching tools [6; 7; 8]. Research also shows that VR technology is particularly suitable to mathematics and science education. VR technology presents concepts in concrete terms and offers a valuable alternative to the conventional study of mathematics and science, which is based primarily on textual descriptions and 2D representations [9].

Technologies, such as VR, can be used to create interactive learning environments where learners can visualize concepts easily and receive feedback to build new knowledge and understanding [10; 11; 12; 13; 14]. VR also supports learning in a nonlinear fashion, which has been shown to be effective in teaching students how to be critical and creative thinkers [15]. Computer simulations have been shown to be an effective approach to improve student learning and have the potential to help students develop more accurate conceptions [16; 17; 18]. Research shows that the use of simulation tools often reinforces learning and leads to performance improvements in a variety of disciplines. Therefore, recently, there has been significant progress in development of computer-based tutorial systems in many different areas.

Though progress has been less evident in engineering education [5], some researchers argue that

Virtual Reality is mature enough to be used for enhancing communication of ideas and concepts, stimulate the interest of engineering students and improve learning. Some noticeable examples of engineering virtual laboratories exist. For instance, Del Alamo [19], a professor of electrical engineering at MIT, created a web-based microelectronics lab for his students in 1998. At Johns Hopkins University, Karweit [20] simulated various engineering and science laboratories on the web. At the University of Illinois Urbana-Champaign (UIUC), researchers developed a virtual laboratory for earthquake engineering [21]. At Purdue University, Richardson and Adamo-Villani [22] developed a photorealistic 3D computer-simulated laboratory for undergraduate instruction in microcontroller technology. Findings form a pilot study with undergraduate engineering students showed that students perceived the VLE experience comparable to the physical laboratory experience and found the virtual lab a useful learning tool.

In the area of surveying, Kuo et al. [23] have recently developed a virtual survey instrument (SimuSurvey) for visualizing and simulating surveying scenarios in a computer-generated VE, and studied the feasibility of introducing SimuSurvey in regular surveyor training courses. Results of the study indicated improved student learning outcomes and positive attitude toward including SimuSurvey in regular surveyor training courses. At Leeds Metropolitan University, UK, Ellis et al. [24] have developed an undergraduate VR surveying application. The interactive software includes 360-degree panoramic images of sites and makes use of QuickTime VR technology. The application was evaluated with 192 undergraduate students; findings suggest that the interactive tool complements traditional learning approaches, maintains student interest, and reinforces understanding. At University of New Castle, UK, Mills and Barber [25] have implemented a virtual surveying field course which includes both a virtual fieldtrip and a virtual interactive traverse learning tool (VITLT). The goal of the tool is to improve understanding of surveying methods for first year students in the Geomatics degree. The application was evaluated by several Geomatics students; all subjects highlighted the potential of VITLT to help the learning and understanding of a traverse. However, the students did not see the e-learning tool as a replacement for a traverse observation as carried out on the field course, but suggested that it could be used as a preparation and revision tool. At Purdue University, Dib and Adamo-Villani [1; 2] have developed a virtual learning environment for teaching and learning the surveying concept of chaining. A pilot study with a group of undergraduate students showed that subjects found the application effective for learning surveying concepts and practices and for getting feedback on their understanding of the subject.

Although some authors have documented that VR experiences provide advantages over more traditional instructional methods [26; 27], studies of VR projects are still relatively rare and a need exists for investigations of VR in the undergraduate classroom.

IV. Development

The VLE module was designed with the intention to replicate the field exercise with high level of fidelity. In the field exercise, the student performs the following steps: (1) select the tools needed to complete the exercise, (2) inspect the site in order to determine the most suitable set up location and target points, (3) set up the instrument, (4) take measurements, (5) record the measurements in the correct tabular format, (6) perform the calculations. The VLE interface requires the user to follow the same exact sequence of activities; figure 1 shows 4 screenshots illustrating the sequence of tasks in the VLE.

Figure 1. The various steps required to perform an accurate measurement in the field. Starting from the top left, frame 1 shows the open field where the surveying exercise is performed; the student selects the location where to set up the instrument and the points of interest. Frame 2 (top right) shows a close up on the machine; the student needs to set it up plumb and on the benchmark. Frame 3 (bottom left) shows a close up on the target where the measurement is taken; frame 4 (bottom right) shows the input table where the student records the measurements.

Moreover, the VLE requires the student to assume all the roles that are usually assumed by the whole team in the field exercise. Therefore, each student has to achieve an acceptable level of competency in all the tasks listed above, without relying on team members for assistance. The VLE does not simplify the real case scenario, as it does not provide the users with default horizontal lines, azimuth and bearings. In the VLE, the users have to identify or calculate the horizontal sight, the bearings and the azimuths by observing all the variables and parameters, as they would be expected to do in the settings of a real field exercise. The VLE is programmed to provide the user with a randomized error within a certain tolerance. It takes into consideration the instruments limitations. Experienced users when replicating a field measurement, assuming that no procedural or user error has been made, expect to get the same answer plus or minus the instrument tolerance, usually referred to the smallest unit of measurement. Any deviation greater than the allowable error needs to be investigated and eliminated, if ruled erroneous. The VLE has been designed with all these embedded details in order to instil in the students the best practices and procedures.

At any time during the exercise, the student can invoke the help of the math tutor (Prof. Acute) who provides explanations of specific math/geometry concepts (figure 2, frames 1, 2). Multiple interconnected representations are included in the VLE to explain more complex math/trigonometry /geometry concepts such as, for instance, how to calculate the coordinates of a point of interest C from two points of known coordinates A & B (Figure 2 shows the different representations). In order to calculate the coordinates of point of interest C, the students need to know the distance between point C and the two other points (A&B), as well as the horizontal angle between the three points. Figure 3 is a zoomed-in image of the symbolic and graphical representations of the required math concepts drawn on the blackboard by Prof. Acute. The image shows (1) the law of cosines which is applied to calculate the angles of the triangle and (2) the trigonometric formula of inverse tangent which is used to calculate the angle [North A,B] using the known coordinates of the two points A & B. Prof. Acute highlights the right triangle using the axes of reference with North-South and East-West passing by the two points A & B. Another set of axes of references North-South and East-West passing by the two points A & C is drawn to highlight another right triangle that will be used to calculate the coordinates of points C.

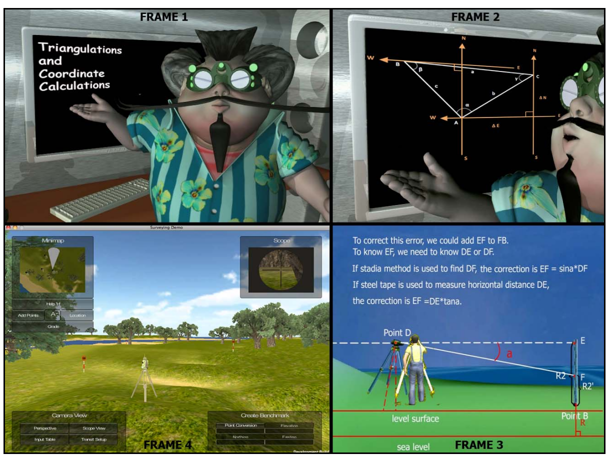

Figure 2. Illustrates how the VLE surveying exercise could improve students' representational fluency in math. In frames 1 and 2 Prof. Acute (the math tutor) explains the law of cosines using a verbal explanation and numeric, symbolic, and graphic representations. Frame 3 is a 3D visualization (concrete representation) that illustrates the application of the law of cosines and Pythagorean theorem in the context of surveying, and highlight the difference between horizontal distance and line of sight distance; frame 4 shows the surveying exercise (real-world application) presented to the students

At the end of the exercise, the VLE provides the student with a detailed performance report. In addition, quantitative data related to students' performance is recorded automatically when the software is used and is forwarded via internet to a central database on the project's server where it can be accessed by the course instructor and evaluator. For instance, data includes students' answers to problems, number of attempts required to perform a particular task, time spent on it, etc.

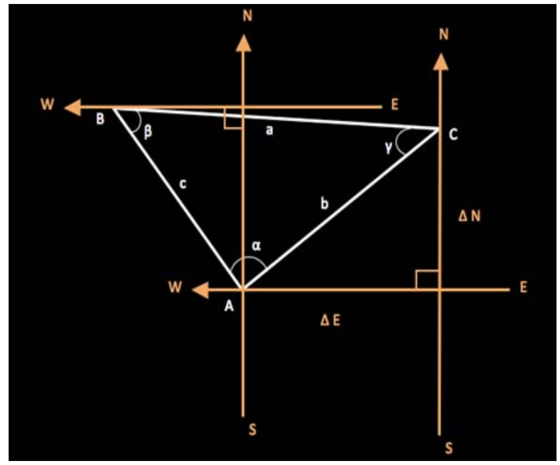

Figure 3. Symbolic and graphical representations of the math concepts used to calculate the coordinates of a point of interest C from two points of known coordinates A & B

4.1. Technical Details

The platform for the VLE is based on Autodesk Maya and Unity3D. Maya software was used to model and texture instruments and characters, and to animate their functionality. Interactivity was programmed in Java using the Unity game development platform. The application is deliverable via web or CD-ROM on standard personal computers (PCs and Macs) and is designed to run on hardware and software infrastructure that is already widely deployed in universities. Students can use the VLE on low-end personal computers (PC/MAC) anywhere anytime.

Generation of the virtual terrains. The VLE presents the students with a variety of terrains to practice on. The virtual terrains are created at run time from DEM (Digital Elevation Model) data. The DEM data is available in a file format (spatial data transfer standard .ddf) that cannot be opened by Unity 3D. In order to import the terrain data into Unity, each DEM file is first opened in the United States Geological Survey (USGS) Global Mapper software, saved as a gray-scale image, imported in Photoshop, exported as a .raw file and saved in a database (e.g. the terrain database). A script imports the .raw file into Unity and reads it as a string into a buffer. By knowing the bit order, the file can be manually parsed and the gray-scale data is used to generate the height-map (with black being the lowest depth, white being the highest); the terrain polygonal mesh is then created at run time from the height map. In order to texture the terrain mesh, each height map vertex is located individually and different textures (e.g. dirt, grass, water, sand, etc.) are assigned based on the height of the vertex. A series of vectors are used at each vertex to calculate how the textures should blend into each other based on the height of the specific vertex. Figure 4 shows a .raw image and the corresponding textured terrain generated in Unity.

To date, the terrain database contains 8 raw images, thus the application provides a selection of 8 terrains on which to practice. More images can be added in the future to provide students with a larger variety of terrains.

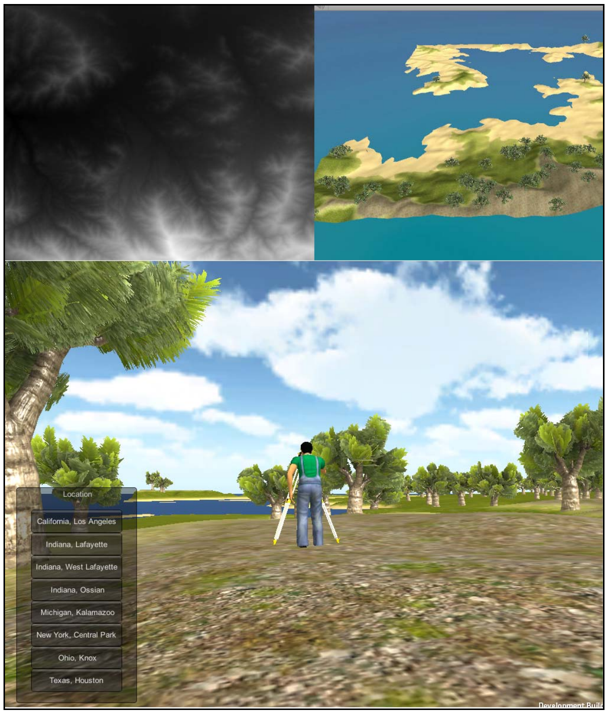

Figure 4. raw image from DEM database (top left); two views of the terrain generated in Unity based on the raw image (top right and bottom)

V. Initial Evaluation

The goal of this initial evaluation was to validate the usability and functionality of the VLE module with a group of experts. The expert panel-based evaluation aimed to assess: (1) usability of the VLE module; (2) quality of 3D graphics and animations; (3) accuracy and fidelity of the virtual instruments; and (4) quality of the educational content. The panel of experts consisted of seven individuals: two experts in VR application development, two experts in 3D modeling and animation, and three experts in Surveying and Surveying Education. Each expert was asked to perform an analytical evaluation of the elements of the application that pertained to his/her area of expertise. The goal of the analytical evaluation was to let the experts perform a variety of user tasks in the VLE, identify potential problems and make recommendations to improve the design. The two experts in VR application development assessed the usability of the VLE module by determining what usability design guidelines it violates and supports.

The usability guidelines used in the evaluation were based on the work of [28; 29]. The experts in 3D modeling and animation were given a questionnaire with questions focusing on the quality of the virtual environments, characters and animations; the experts in Surveying were given similar questionnaires with questions on the fidelity and accuracy of the virtual instruments and quality of the surveying and math exercises. The evaluators used a five point Likert scale for rating the response to each question (1= low; 5=high), and used comment boxes to provide additional feedback.

Overall, the application was found easy to use (MEAN=4.5) and all evaluators were able to complete the users' tasks without difficulty. However, one evaluator commented that the camera controls are not intuitive, and it takes too much time to learn how to use them. The quality of the 3D terrains, characters and animations was rated very high by the experts in 3D graphics (MEAN=5) and, therefore, recommendations for improvement were not necessary.

The virtual instruments were found accurate (MEAN=4.5) and comparable to the physical ones (level of fidelity: MEAN=4). One evaluator commented that the angle, currently reported in degrees and decimals, should be reported in degrees minutes and seconds in order to be true to real surveying equipment.

The quality of the surveying exercise and math representations were rated very high (MEAN=5); one faculty commented that "*The VLE replicates the field exercise exactly*".

VI. Conclusion and Future Work

In this paper we have described the design, development and initial evaluation of one of the 5 modules of the VELS [1; 2; 3], a virtual environment for teaching/learning surveying concepts and practices. The module discussed in the paper focuses on Triangulations and Coordinates Calculations and allows students to learn and practice proper techniques for working with the transit to measure angles and distances and hence calculate the coordinates and elevations of the points of interests. An initial evaluation with a panel of experts in VR application development, computer graphics and surveying/surveying education validated the usability, functionality and potential educational efficacy of the tool.

The proposed VLE overcomes many of the problems faced by traditional surveying instruction. It provides students with 24/7 access to surveying equipment and practice exercises; allows for surveying education at distance; provides immediate feedback on students' performance; provides assistance and guidance in the learning process; allows for less dependency on team members (students are able to work individually and at their own pace); gives access to "standardized" virtual equipment (this eliminates the risk of working with erroneous equipment); and has the potential to increase students' math competence - students will improve their representational fluency in math by being exposed to multiple interconnected representations (i.e. concrete, numeric/symbolic, textual, pictorial, real-world representations) of mathematics, geometry and trigonometry concepts in the context of surveying.

Future work will include refining the VLE module based on the experts' recommendations, completing the development of module 5, and conducting formative and summative evaluations with target users.

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