An Innovative Software Application for Surveying Education

HAZAR DIB,¹ NICOLETTA ADAMO-VILLANI²

¹Computer Graphics Technology/Building Construction Management, Purdue University, West Lafayette, IN
²Computer Graphics Technology, Purdue University, West Lafayette, IN

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ABSTRACT: We present an innovative educational computer application for undergraduate students enrolled in a Construction Surveying Fundamentals course. The application includes an Interactive Virtual Environment for learning surveying concepts and practices, and an e-assessment tool that measures the individual student’s cognitive and practical abilities. Results of a pilot study with 31 undergraduate students and 2 faculties showed that the software was perceived as easy to use, useful, and effective at measuring the individual student’s performance. © 2011 Wiley Periodicals, Inc. Comput Appl Eng Educ; View this article online at wileyonlinelibrary.com/journal/cae; DOI 10.1002/cae.20580

Keywords: surveying; virtual learning environments; e-assessment tools; engineering education; computer graphics technology

INTRODUCTION

Surveying is “…the science and art of making all essential measurements to determine the relative position of points and/or physical and cultural details above, on, or beneath the surface of the Earth, and to depict them in a usable form, or to establish the position of points and/or details…” [1].

In addition to determining the three dimensional characteristics of the earth’s surface by the measurements of distances, directions, and elevations, surveying also involves staking out lines and grades needed for the construction of buildings, roads, dams, and other engineering structures. Furthermore, surveying is used for the computation of areas, volumes, and other quantities, as well as the preparation of maps and diagrams.

Surveying has many industrial applications including setting equipment, assembling aircrafts, and laying out assembly lines. Engineers, architects, foresters, and geologists use surveying for their projects. In large-scale mapping, adjustments are made to the curvature of the earth; this is referred to as geodetic surveying. On small areas, plane-surveying concepts are applied. In plane surveying the earth is considered flat and both simple plane geometry and plane trigonometry are used.

Surveying requires the use of many specialized tools and instruments including levels of several types—mechanical and optical; transits—pocket transits as well as optical and laser styles; the plane or map table with different alidade types; theodolites—both optical and laser; electronic distance measuring equipment, global positioning system (GPS), electronic data collectors, hand-held calculators; computer and satellite radio and GPS interfaces; prism and mirror reflectors; rods and stadia boards; surveyor’s measuring tapes; plumb bobs—including low-light or miner’s plumb bobs as well as laser plumb devices, and a variety of recording equipment. Other commonly used tools are slide rules, mapping tools, and text or paper-based media when the machines fail for one reason or another. Computer hardware and software are becoming more and more prevalent in surveying and it is not uncommon to see instruments with Bluetooth wireless enabled interfaces.

In general, in a surveying course students learn the theoretical foundation of surveying, as well as how to operate the instruments. They learn to think logically, work with accuracy and precision, and record the work in a neat and orderly fashion. They develop a good understanding of proportions and acquire essential habits of checking numerical calculations and measurements.

In this article, we describe an innovative software application for undergraduate surveying education. The application focuses on plane surveying in the context of construction layout, where angles, distances, and elevations are used to set up the building footprint at the correct location, establish level elevations, and plumb vertical surfaces.
Specifically, the work reported in the article addresses the need to create effective learning environments and e-assessment tools to enhance surveying education. The project’s long-term goal is to use emerging computer graphics technologies to develop and validate innovative educational technologies that support students learning and evaluation and lead to effective instructional approaches in the engineering curriculum.

The article is organized as follows: in the second section we discuss the challenges faced by traditional surveying instruction; in the third section we report prior work on virtual learning environments for engineering education and we discuss and review examples of e-assessment tools. The design and development of the software are described in the fourth section and the pilot study is discussed in the fifth section. Conclusive remarks and future work are included in the sixth section.

THE NEED

Surveying is a fundamental course in the Civil Engineering, Building Construction Management, Geomatics, Agriculture & Forestry, and Landscape Architecture curricula. 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. (3) Student practice (in groups) with real instruments.

This traditional way of teaching construction surveying presents several challenges such as limited students’ access to instruments, limited availability of terrains on which to practice, dependence on weather conditions, need for one to one training, difficulty in assessing the individual student’s performance with accuracy.

One of the authors has taught the surveying course over 30 times and has observed over 750 students; Students’ feedback revealed that (1) 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, (2) additional time to practice with the equipment, (3) less dependence on team members, (4) immediate feedback on accuracy of measurement, and (5) 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 assess the individual student performance in settings where the nature of the exercises requires collaboration between at least two students. For instance, exercises that involve tape measurements, use of level to measure differential elevations, or theodolites to measure angles and distances are tasks that need to be completed by two or more students working closely together. The only exception is the use of GPS equipment, since students can perform the tasks individually without the help of other team members. It is difficult to evaluate the 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 teammate.

From a logistics perspective, it is very common to have one professor working with a large group of students. Ideally, effective surveying instruction would require one to one training; for obvious reasons, this is not practical or feasible.

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.

Finally, traditional surveying instruction provides very limited practice opportunities for physically disabled students. Students with a visual impairment and/or limited motor skills are deprived of quality training with instruments, as many surveying exercises require high level of dexterity and good vision. At most, disabled students with reduced motor skills can watch their partners perform the exercises [4].

Kuo et al. [2] argue that surveying training can be significantly improved with the use of digital teaching aids and virtual tools. The goal of the work described in the article is to enhance traditional surveying instruction methods with a unique approach: an engaging, interactive computer application comprising a virtual learning environment (VLE) with surveying instruments that look, operate, and produce results comparable to the physical ones, and an evaluation engine that tracks the student’s interactions with the program and outputs performance reports. The software is not meant to replace field practice completely; it will be integrated in surveying courses as a preparation, revision, and e-assessment tool.

Our software will solve many of the problems associated with current surveying instruction by providing: (1) 24/7 access to surveying equipment and practice exercises; (2) surveying training at distance; (3) formative and summative assessment of students’ performance; (4) assistance and guidance in the learning process; (5) less dependence on team members (students are able to work individually and at their own pace); (6) access to “standardized” virtual equipment (this eliminates the risk of working with erroneous equipment); and (7) instrument accessibility to students with motor and vision impairments.

BACKGROUND

Interactive Virtual Environments and Learning

An Interactive 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, that is, 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 [6–8]. Research also shows that VLEs are particularly suitable to mathematics and science education. VLEs present concepts in concrete terms and offer 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 Virtual Reality can be used to create interactive learning environments where learners can visualize concepts easily and receive feedback to build new knowledge and understanding [10–14]. VR also supports learning in a non-linear 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 [16–18]. 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.

Some noticeable examples of engineering virtual laboratories can be found in the literature. 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] has simulated various engineering and science laboratories on the web. At the University of Illinois Urbana-Champaign (UIUC), researchers have developed a virtual laboratory for earthquake engineering [21].

In the area of surveying, Kuo et al. [2] 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. [22] have developed an undergraduate VR surveying application. This interactive software includes 360° 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 [23] have implemented a virtual surveying field course which includes both a virtual fieldstrip 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.

Although some authors have documented that Virtual Learning Environments provide advantages over more traditional instructional methods [24,25] studies of VR projects are still relatively rare and a need exists for investigations of VLEs in the undergraduate classroom [15].

e-Assessment Tools

The term e-Assessment is becoming widely used as a generic term to describe the use of computers within the assessment process. In general, e-assessment tools provide two forms of assessment: formative and summative. Formative assessment constitutes a learning experience in its own right and is concerned with the provision of developmental feedback to the learners such that students can gain from the feedback provided and adjust their learning style as appropriate [26]. Summative assessment is usually undertaken at the end of a period of learning in order to generate a grade that reflects the student’s performance.

According to Howarth [26] e-Assessment has many advantages over traditional paper-based assessment including: lower long-term costs, instant feedback to students, greater flexibility with respect to location and timing, improved reliability (machine marking is much more reliable than human marking), and enhanced question styles which incorporate interactivity and multimedia. Public and private sector experts have stated that computers, telecommunications, audio, or video based media are critical enablers of learning, hence there is a need for assessment tools that measure those essential skills that cannot be captured by traditional tests [27]. Fogel [28] argues that e-Assessments provide the essential feedback for true 21st century education transformation in which student outcomes can be correlated to a cause-and-effect and in which there is continuous improvement of the e-Learning environment.

There are also disadvantages. e-Assessment systems are expensive to establish and not suitable for every type of assessment (such as extended response questions). Educators need specific skills to create e-assessment resources, and producing e-assessment tools is a time-consuming process.

Recently, several researchers have focused on development and evaluation of e-assessment tools for college-level learning. Doukas et al. [29] have presented a computer-aided summative assessment system (e-Xaminer) to produce and deliver tests to the Hellenic Air Force Academy students and assess their performance. e-Xaminer uses meta-language concepts to generate tests based on parametrically designed questions. Examinations are delivered via a web-based interface and the system grades the answers submitted by each student. e-Xaminer also allows for implementation of question parameterization and counter cheating measures. The researchers conducted a pilot study that compared paper-and-pencil exams versus the electronic exams in digital electronics, computer science, microprocessors, and computer network courses. Results showed that the deviation between the manually graded tests and the electronically graded ones was <1%. Over 90% of the students thought that the electronic test was equally difficult and preferable to the traditional one. In addition, students expected their automatically assigned marks to better reflect their performance.

Perry et al. [30] report a project whose goal was to introduce and evaluate a hybrid formative/summative e-assessment tool in an introductory course in Chemical Engineering. The e-assessment tool was created using Respondus [31] and the e-tests were delivered by WebCT4. Answers from a questionnaire completed by tutors and students showed that over 80% of the students found the feedback provided by the e-assessment tool to be very useful and helpful in determining the areas of learning that needed improvement. Tutors noted that the e-test saved about a day’s work and had the main advantage of allowing students to take the test from home.

Andreatos et al. [32] describe a Matlab-based e-assessment application for an introductory course in analog electronic design. The application included a student interface and an instructor interface. Students designed a transistor amplifier and provided their answers through their interface, and the instructor could automatically evaluate the student answers.
qualitatively and quantitatively. Moscinski [33] reports examples of using Moodle-based tools for summative e-assessment. The e-assessment tools were tested in both theoretically oriented courses on control systems, as well as software and technology oriented courses on computer networks and Internet technologies. The questionnaire-based analysis demonstrated the popularity and efficiency of the e-assessment tools and methods both among students and teachers.

APPLICATION DESIGN AND DEVELOPMENT

To date, the surveying software tool includes one educational module (i.e., chaining); the final application (under development) will include four educational modules that are specifically designed to address the students’ learning challenges outlined in Table 1. The modules are based in part on Kavanagh [34] and McCormac [35].

Technical Implementation

The VLE can be delivered via web or CD-ROM on standard personal computers with low-end graphic cards. The platform for the project is based on Microsoft XNA. Interactivity was programmed using C#: all graphic components were created using Adobe Illustrator and Autodesk Maya 2011. Figure 1 shows two flowcharts illustrating the program logic.

Application Components

The application consists of two components: (1) a Virtual Learning Environment (VLE) that is used by the students to review concepts and procedures and perform surveying exercises; and (2) an evaluation engine that tracks the student’s interactions with the program and outputs performance reports.

(1) The educational content of the student VLE focuses on chaining. The goal of this first educational module is to help students visualize and apply the concepts of chaining in the following scenarios: horizontal plane, steep slope, rough terrain, error of standardization of steel tape, error due to temperature, and error due to both temperature and standardization. The VLE includes reference documentation on surveying methods and the students learn and practice how to measure the horizontal distance between two points using the proper techniques and instruments. Students are required to use one or several of the following instruments: steel tape to measure the distance between the two points of interests; plumb bobs to set the tape at the points of interests; hand levels to make sure the steel tape is leveled (i.e., the students are measuring the horizontal distance not the slope); tension meter to make sure that the tape is at the correct tension; pins, to mark the points on the ground, so that the measurements can be repeated multiple times. Students are expected to measure the horizontal distance precisely and accurately. Measurement is classified as precise, when students are able to repeat the same measurement multiple times and get the same value or a value with a small acceptable variation (this variation is due to the limitation of the instruments). Accuracy is achieved when the same value is obtained multiple times and that value is the true value, or a value within an acceptable variation.

The VLE has been programmed to allow for 1/16th of an inch variation, that is, if the student sets up perfectly at the point of interest two times in a row, the plumb bob is within 1/16th of an inch from the previous location (this replicates real life settings where the plumb bob will be swinging and will always be at a very small distance from the point). If all the criteria are followed correctly, two consecutive measurements will vary within a 1/8th of an inch. Hence, in the VLE, precision is reached if the same measurement or measurements within 1/8th of an inch or 1/100th of a foot are achieved multiple times. Accuracy is achieved by

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Students’ Common Learning Challenges in Surveying</th>
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<tbody>
<tr>
<td>Theoretical Challenges</td>
<td>Practical Challenges</td>
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<tr>
<td>(1) Chaining</td>
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<tr>
<td>Correction error due to temperature changes</td>
<td>Error due to alignment</td>
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<tr>
<td>Correction due to tension and sag in tape</td>
<td>Break down the distance method</td>
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<tr>
<td>The concept of measuring horizontal distance vs. slope distance</td>
<td>Using the plumb bob properly</td>
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<td>Use of chaining pins</td>
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<tr>
<td>(2) Differential leveling</td>
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<tr>
<td>Concept of differential leveling</td>
<td>Proper instrument set up</td>
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<tr>
<td>Calculation of error</td>
<td>Choice of tripod location</td>
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<tr>
<td>Filling the tabular information</td>
<td>Holding the measuring rod properly</td>
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<tr>
<td>Maximum allowable error</td>
<td>Reading the measuring rod properly</td>
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<tr>
<td>Distribution of error</td>
<td>Safe field practices/practice common sense</td>
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<tr>
<td>(3) Triangulations and coordinates calculations</td>
<td></td>
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<tr>
<td>Mathematics and trigonometry background</td>
<td>Proper instrument set up</td>
</tr>
<tr>
<td>Concepts of vectors</td>
<td>Techniques for proper set up on a benchmark</td>
</tr>
<tr>
<td>Calculation of coordinates based on angles and distances</td>
<td>Proper techniques to read the horizontal and vertical angles</td>
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<tr>
<td>Traverse calculation</td>
<td>Finding True North</td>
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<tr>
<td>Distribution of error</td>
<td>Safe field practices/practice common sense</td>
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<tr>
<td>Use of Robots &amp; GPS equipment</td>
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<tr>
<td>Traverse calculation</td>
<td>Proper instrument set up</td>
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<td>Safe field practices/practice common sense</td>
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Figure 1  Flowcharts illustrating the program logic. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]
repeating multiple measurements and therefore compensating for the random 1/8th of inch variation created by the software. Screenshots of the student VLE are shown in Figure 2; a video demonstration of the program can be viewed at: http://www2.tech.purdue.edu/cgt/i3/VELS/.

(2) The evaluation engine tracks the student’s interactions such as (a) the student ability to select the correct tools; (b) the student ability to set up at the correct point of interest; (c) the student ability to hold the tape horizontally, therefore the level has to be perfectly plumb; (d) the student ability to exert the correct amount of tension on the tape, so that the tape can read the horizontal distance; (e) the reading on the tape as a record of the students measurements; (f) the student decision to delete or retain a specific reading (this is used to evaluate the student interpretation of the results); (g) the time spent on each task; (h) the number of correct and incorrect answers. The evaluation engine outputs two types of reports: a summary report that provides formative feedback to the student (Fig. 3) and a detailed performance report for the instructor in the form of an excel spreadsheet. The instructor uses this report to generate the final grade.

Key Features of the Application

Key features of the software include: (a) Open content; (b) Digital Elevation Model (DEM) data support; (c) a virtual math tutor; and (d) universal access for students with disabilities.

(a) Open content. The software has an open architecture that supports flexible customization. Educators will be able to easily modify existing content and add new educational modules to fit the needs of the course.

(b) DEM (Digital Elevation Model) data support. The software will support import of DEM data and will allow for real-time generation of virtual terrains based on these data. This feature (under development) will provide students with a large selection of terrains they can practice on.

Figure 2 Screenshots of the student’s VLE. Clockwise from top left: tool selection screen with feedback to student; tool adjustments with feedback to the students (case of failure to achieve proper adjustments two consecutive times); recording of the tape measurement; option to review multiple measurements and delete outlier or erroneous ones. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]
Virtual math tutor. The VLE includes an animated math tutor that students can invoke anytime during the learning/practice sessions. The tutor (Professor Acute) provides math explanations, tips, formulas, and guidelines on how to apply math concepts to obtain precise measurements.

Universal Access for students with disabilities. In 1999, the U.S. Department of Education’s National Center for Education Statistics (NCES) reported that an estimated 428,280 students with disabilities were enrolled at 2- and 4-year postsecondary educational institutions. The software is designed to meet the needs of these students, specifically those with permanent and temporary impairments such as limited vision and limited motor skills. The software is being developed according to the policy of the U.S. Department of Education—National Institute on Disability and Rehabilitation Research [36], and the Accessible Digital Media Guidelines established by the National Center for Accessible Media [37]. Specifically we will consider guidelines A (images), E (interactivity), F (graphs), G (math), and H (multimedia). In addition, the software supports specialized input devices in order to meet the needs of students with limited dexterity.

PILOT STUDY

The objectives of the study were to: (1) collect feedback from the students on the usefulness and usability of the application; (2) determine the effectiveness of the software as an e-assessment tool; (3) collect feedback from the surveying instructors on the perceived effectiveness and accuracy of the application as a learning and assessment tool, and (4) determine if there are differences between results students achieved by manual surveying in field, and via the application.

Subjects

The pool of subjects included 31 male undergraduate students and two faculties with experience in surveying education. The students were enrolled in a Construction Surveying Fundamentals course in the College of Technology at Purdue University. The course is designed to develop the surveying skills necessary to measure horizontal and vertical distances, differences in elevations, horizontal and vertical angles, and to compute tape corrections, traverses, and layout data. Emphasis is placed on accuracy of measurements, precise operation of instruments, completeness in performing laboratory exercises, and keeping accurate field notes. The subjects who volunteered to use the software were students who needed additional credits to improve their grades in the class.

Procedure

The goal of the exercise presented to the students was to measure the horizontal distance between two points with the required precision and accuracy. The subjects performed the chaining exercise in two settings: (1) in the field and (2) in
the surveying lab using the application. The instructors graded the exercise in both settings.

Setting (1). The students measured the horizontal distance between two points marked on the ground with the help of a colleague. Students used a steel tape, plumb bobs, tension meter, hand levels, and hand clamps and had to ensure that the tape was held horizontally at the two points and the correct amount of tension was exerted in order for the tape to be correctly stretched between the two points. The students recorded their measurements, adjusted for temperature and tape standard error, and reported the measurements in a logbook. The ability of the instructor to observe in great details the individual students methods and procedures is not feasible due to the settings of the exercise, where at least two students are involved in every individual experiment. In order to limit the time spent performing the testing, and due to the number of the students enrolled in the class, the students worked simultaneously in groups. The instructors timed the exercises and compared the recorded values to the correct values. The students were graded based on how close their final measurement was to the true value.

Setting (2). The students were first given guidelines on how to use the program; they were then provided with a set of directions and assumptions for the chaining exercise. The goal of the exercise was to measure the horizontal distance between points A and B with precision and accuracy—the tool presents six possible points. The following assumptions were to be considered: the terrain is a rough terrain, the temperature is 86°F, and the error in the tape is 1/100th percent short, that is, when the tape measures 100 ft it is in reality 99.99 ft. The students were instructed to use e-assessment tool to measure the distance multiple times and recorded their results and their understanding of concepts and practices. Accuracy is given by how close a measurement is to the true value; precision refers to how close one measurement is to another, that is, a high level of precision is achieved when the values obtained my measuring the same distance multiple times are very close to each other.

In both settings, the students’ grades were determined based on the same parameters: the accuracy and precision of their measurements. Accuracy is given by how close a measurement is to the true value; precision refers to how close one measurement is to another, that is, a high level of precision is achieved when the values obtained my measuring the same distance multiple times are very close to each other.

In setting 1 (the field), the actual distance was measured with a total station or electronic theodolite. Such instrument can measure distances with an accuracy of about 1.5 mm (0.0049 ft) + 2 parts per million over a distance of up to 1,500 m (4,900 ft). The students used the steel tape to measure the distance multiple times and recorded their results and attempts on an engineering paper, along with a sketch of the points, the various values measured, the calculated average distance, the probable error or relative error, and the degree of precision.

In setting 2 (our software), the students followed the same procedure as in setting 1, and used virtual instruments that operate and have a level of accuracy comparable to the physical ones. However, students did not have to report their results and attempts on paper, this task was performed by the software, and all data were saved to a file accessible to the instructor.

In addition to recording accuracy and precision, the software is able to track other students’ activities (see Table 2). While these additional data recorded by the software were not used as parameters to determine the grade, they provided the instructors with useful insight about the students’ performance and their understanding of concepts and practices.

### Analysis and Discussion of Results

#### Students’ Observations

The answers to the questionnaire show that 76% of the students thought the application was a good

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<td>First time correct tools selection</td>
<td>With excess tools</td>
<td>Retried tools selection</td>
<td>First time correct procedure</td>
<td>Retired procedures</td>
<td>With more than two readings</td>
<td>With deleted readings</td>
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<td>Field Lab</td>
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<td>Student individual effort</td>
<td>Plumb X axis correct</td>
<td>Plumb Z axis correct</td>
<td>Level correct</td>
<td>Tension correct</td>
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<td>Field Lab</td>
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#### Table 2

Students’ Activities Tracked by the Software Versus Activities Recorded by the Instructor During the Field Exercise

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<td>Time to completion</td>
<td>Average measurement</td>
<td>Number of repetitions</td>
<td>Number of deleted measurements</td>
<td>True measurements</td>
<td>Adjustment for error</td>
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<tr>
<td>Field Lab</td>
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learning tool, as it helped them visualize fundamental steps and procedures. Seventy-six percent of the students thought it was very helpful in terms of capturing the essence of the chaining exercise and 40% felt that it replicated the field exercise with accuracy. However, 60% of the students commented that the tool cannot replace the actual field experience. Sixty percent thought it was a good practice tool and some of them recommended that it should be used in the classroom for review and practice. Twenty-eight percent thought it is easy to use, while 8% felt it was difficult at first. Eight percent of the students observed that the software allowed them to think ahead about every step they needed to make.

Electronic Grades Versus Manual Grades. Figure 4 shows that the student average e-grade (i.e., the grade obtained with the software) was 65%, whereas the student average m-grade (i.e., the manual grade resulting from the field exercise) was 75%. Figure 5 compares the frequency of the grades by letter grade. The same number of students, who achieved an “A” in the field test, earned the same grade using the software. One out of four students was able to earn a “B” in the field exercise and achieved the same grade using the application. None of the students earned an “F” as m-grade while nine students earned an “F” as e-grade.

A weighted kappa measure of agreement, a paired t-test, and a sign test were performed in order to determine any correlation between the students’ grades obtained by manually grading the chaining field exercise and the grades obtained with the software tool. All three tests show that there is weak agreement between the two sets of grades.

Weighted Kappa Measure of Agreement. Table 3 shows the strength of agreement between the e-grades (i.e., the grades obtained with the e-assessment tool) and m-grades (i.e., the manually calculated grades earned in the field exercise).

Table 4 shows the weighted Kappa for measuring agreement between the two tests. When “Kappa = 0,” the degree of agreement that the data exhibit is no better than the one expected by chance. “One-sided Pr K,” or so-called “P-value,” is a probability that observes data that show a nonindependent pattern (i.e., larger kappa value) than the current data under the hypothesis “Kappa = 0.” In general, if the p-value is small (<0.05 or <0.01), we reject the hypothesis “Kappa = 0” because if the P-value is that small, the current data are very unlikely to happen under “Kappa = 0.” Hence, we conclude that Kappa is not actually 0 but other value. “Exact Test” is used when the sample size is not large and therefore asymptotic assumptions are not met. The P-value of “Exact test” is calculated by enumerating all possible tables with the same fixed marginal frequencies as the current table (tables that have the same row frequency and column frequency as the current table), and accumulating the probabilities for all tables that produce a kappa index that is greater than or equal to the current kappa value. Since the P-value is very small, it is difficult to say that Kappa = 0. In fact, it rarely happens that the degree of agreement is no better than the one expected by chance. Hence, rather than conducting testing, it is recommended to use kappa as index or descriptive statistic measuring the strength of agreement.

Based on the weighted kappa value, we can say the agreement between m-grades and e-grades is weak.
Although the larger the Kappa, the stronger the agreement, nonzero kappa and small \( P \)-value do not necessarily mean that agreement “exists”. For example, Table 5 is a contingency table showing responses (1 = strongly disagree, 2 = disagree, 3 = agree, 4 = strongly agree) to e-assessment tool and field test from a matched data. The weighted kappa of these data is 0.0157 (\( P \)-value = 0.0001). The data show very weak agreement (otherwise there would be larger values on diagonals).

A Sign-test was used to determine whether the difference between the m-grades and e-grades was significant (Table 6). The Sign-test is a nonparametric method that counts the number of cases where the m-grades are higher than the e-grades and the number of cases where e-grades are higher than m-grades. If there is no difference between e-grades and m-grades, the two numbers would be very similar; and if some difference exists, then either one of two numbers is larger than the other.

In this test, the \( P \)-value (\( Pr \geq |M| \)) was also very small, so we could conclude that e-grades and m-grades are different and, specifically, m-grades tend to be higher than e-grades.

We believe that the disagreement between the m-grades and e-grades (the m-grades were generally higher than the e-grades) might be due to one or several of the following factors.

- Students worked in groups in the field setting, while they were required to work individually with the software.
- In a group setting, less prepared students benefit from the assistance of more capable students and hence they have a higher chance of earning a better grade.
- Whereas students practiced extensively throughout the semester with the real instruments, they did not practice as much with the software, as the program was presented to them at the end of the semester. This limited familiarity with the software interface might have had a negative impact on their performance within the program.
- Some students commented that the software would not allow them to get the plumb bob exactly at the point, and the tension was not very accurate at 20 lbs pull. They felt that these imperfections prevented them from achieving high accuracy and precision. We note that these imperfections were intentionally designed within the program to simulate a real case scenario. In the field, the wind or other conditions can cause the plumb bob to swing slightly above the point, resulting in a slight variation in the measurements. In addition, in real life it is very difficult for an individual to maintain a steady 20 lbs pull force on the tape. The students did not seem to be concerned with the lack of precision in the field but pointed it out while using the software.

**Instructors’ Observations.** The instructors commented that the software was able to calculate the individual students’ grades based on a very thorough report of their performance. Students were assessed based on their ability to select the correct tools the first time, ability to select correct procedures the first time, making more than two readings in order to eliminate the random error generated by the instruments errors, and making the correct judgment by deleting the erroneous and outlier measurements if the deviation was larger than the allowable instrument errors. In the field exercise it was not possible to track all these factors. For instance, students selected the required tools and performed the measuring procedures with a colleague; hence it was not possible to analyze the individual student performance.

**CONCLUSION AND FUTURE WORK**

In this article we have described the development of a software tool for surveying instruction and we have reported the findings of a user study with 31 undergraduate students. The results of the pilot study are promising. Students found the program useful for learning and providing formative feedback on their level of understanding of chaining concepts and procedures. Instructors commented that the software is a very effective summative assessment tool that allows educators to calculate a grade that truly reflects the individual student’s performance. These findings support our hypothesis that the fully developed application has the potential to enhance the quality of surveying instruction by solving many of the problems associated with traditional teaching methods.

Future work will involve extending the content of the application to include three additional teaching modules (i.e., Differential Leveling, Triangulations and Coordinate calculations, Current technologies in Surveying), and evaluating the e-tool with a larger sample size.

We will also investigate the possibility of integrating the application in an open-source Learning Management System (LMS) such as ATutor (http://atutor.ca/atutor/) or OLAT (http://www.alliedlearningsolutions.com/olat.html).

**REFERENCES**


[21] Smart Structures Technology Laboratory (SSTE) at UIUC Virtual Laboratory for Earthquake Engineering, 2008, Available at: http://sstl.cee.illinois.edu/.


BIOGRAPHIES

Hazar Dib is Assistant Professor with a joint appointment in Computer Graphics Technology and Building Construction Management at Purdue University. He has an MS in Civil Engineering from University of Balamand, Lebanon and a PhD in Construction Management from University of Florida, USA. His area of expertise is in visualization and information Management. His research interests are in (1) visualization, organization, documentation and communication of information in the context of Building Construction Management; and (2) design, development and validation of innovative teaching technologies for engineering education.

Nicoletta Adamo-Villani is Associate Professor of Computer Graphics Technology at Purdue University and a University Faculty Scholar. She has an MS in Architecture from University of Florence, Italy and she is a certified animator and instructor for Autodesk. Prof. Adamo-Villani is an award-winning animator and graphic designer and creator of several animations that aired on national television. Her area of expertise is in character animation and character design and her research interests focus on the application of computer animation technology to education, HCC (Human Computer Communication), and visualization. Nicoletta is co-founder and co-director of the IDeaLaboratory.