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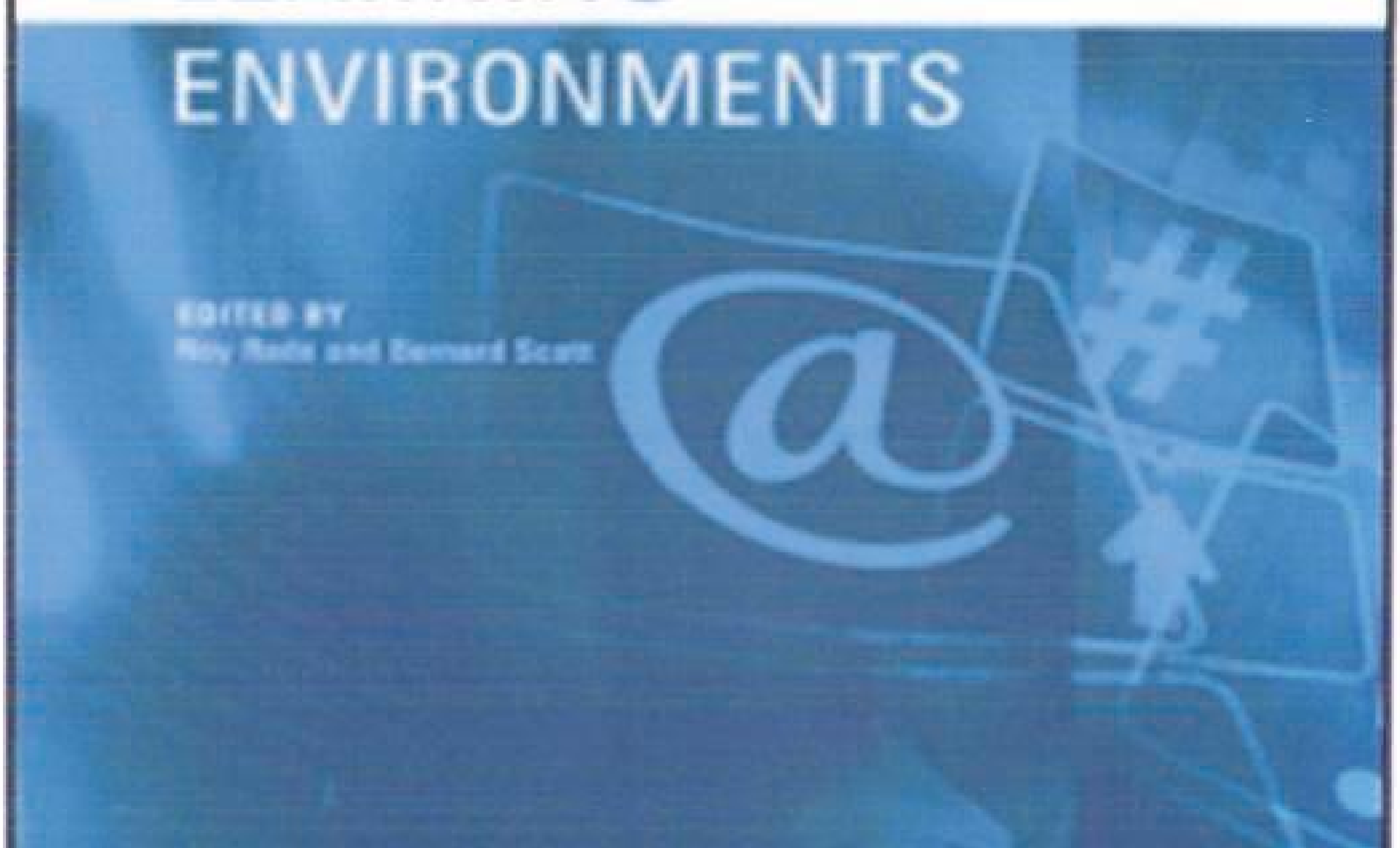

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Abstract: The use of professional software is an integral part of a student's education in the mining engineering curriculum at The Pennsylvania State University. Even though mining engineering represents a limited market across U.S. educational institutions, the goal still exists for using this type of software to enrich the learning environment with visual elements and, therefore, enhance the students' ability to understand design principles in a more systematic manner. All of the students are required to develop a complete mine-design project, from conception to completion, which includes the selection of appropriate mining components and systems to meet desired needs. However, the question that is often asked is whether or not the desired benefits from using such software can be justified in terms of initial cost, and programming time required for both the instructor and students of small engineering programs, such as mining engineering. The objective of this paper is to evaluate the experiences of faculty and students with typical professional software tools available for mining-engineering educational programs, and to assess their ability to enhance active teaching and learning through computer-based problem solving in a manner which is cost effective for a small-enrolment engineering major.

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The Effective Use of Professional Software in an Undergraduate Mining Engineering Curriculum

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The use of professional software is an integral part of a student's education in the mining engineering curriculum at The Pennsylvania State University. Even though mining engineering represents a limited market across U.S. educational institutions, the goal still exists for using this type of software to enrich the learning environment with visual elements and, therefore, enhance the students' ability to understand design principles in a more systematic manner. All of the students are required to develop a complete mine-design project, from conception to completion, which includes the selection of appropriate mining components and systems to meet desired needs. However, the question that is often asked is whether or not the desired benefits from using such software can be justified in terms of initial cost, and programming time required for both the instructor and students of small engineering programs, such as mining engineering. The objective of this paper is to evaluate the experiences of faculty and students with typical professional software tools available for mining-engineering educational programs, and to assess their ability to enhance active teaching and learning through computer-based problem solving in a manner which is cost effective for a small-enrolment engineering major.

1. Introduction

Over the last 40 years, computers have increasingly played more integral roles in mining activities. They have been used in all areas of mining, from exploration to mine planning and design, mine operations, reclamation, surveying, maintenance, inventory control, GPS applications, and so forth. The main objective of computer applications is to simplify the process of storage, retrieval, and analysis of mining data, facilitate the design, simulation, and monitoring of mine plans and mining operations, and to assist engineers in the day-to-day decision-making process (Badiozamani, 1996). Prior to the mid-1970s, computer applications for mining engineering were limited, due to high costs, inefficient hardware and software, the requirement for highly skilled computer programmers, and the inability of software to

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address complex problems beyond a single task (Hladysz, 1996). During that time, most software development was conducted at universities and focused on research-supported programs, such as Virginia Tech's FACESIM, an underground coal mine production simulator, and The Pennsylvania State University's (henceforth Penn State) UGMHS (Underground Materials Handling Simulator) and Mine Ventilation Simulator. Since these were produced through supported research, they were widely disseminated through the mining industry for those companies with mainframe computer capabilities. Since these programs were developed at universities, they became integral components in the undergraduate mining engineering curricula.

The explosion of technical computing in the 1980s and early 1990s stimulated the development of new hardware and software capable of addressing multiple problems and tasks, and smaller and more powerful computers, in a more cost-effective computing environment (Wilkinson, 2002). Since then, new algorithms and software tools have been developed to solve the most difficult mining problems while, at the same time, hardware has been developed to enable these tools to run faster and more efficiently. As computer technology evolved and increased in sophistication and power, a new frontier and dimension opened, which is limited only by the user's imagination. Utilizing an interactive three-dimensional (3-D) graphical environment, multiple tasks can now be solved. Providing a visual design allows the user to test operational ideas and identify problems before they are reached operationally in a real setting where an error can be quite costly. Likewise, the visual environment communicates crucial planning concepts to mine-operations individuals in a format that can be readily understood. Complex calculations can be performed quickly, allowing simulation modelling to provide accurate representations of real mining situations and, as a consequence, can be analysed before making substantial investments. Computer-aided design (CAD) packages have changed most engineering curricula, making it possible for users to analyse and design at levels of precision considered extremely difficult to accomplish by hand calculations, alone (Philpot, 2000). For classroom instruction, the use of PCs and projection equipment, coupled with recently developed software and spreadsheets, enables mining-engineering educators, for the first time, to conduct mine-design classes with real-time discussion of the effects created by varying input parameters.

The mining industry's need for engineers educated and trained in the latest software has significantly increased in the last decade. Thomas, Jarosz, and Kuruppu (2003) state that the mining industry is a large consumer of advanced software and, while university courses should always concentrate on the underpinning "theory" and not on software design, these "tools" need to be integrated into the curriculum in the same way that they are considered to be integral parts of day-to-day site operations. Also, accredited mining engineering programs are required to comply with the Accreditation Board of Engineering Technology's (ABET's) program criteria which states that students are expected to develop an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Recognizing these requirements, the integration of professional software into Penn State's mining engineering program is an important part of a student's education.

The following sections of this paper demonstrate how to take advantage of, and assess, currently available cutting-edge software to educate the next generation of mining-engineering professionals.

2. Currently Available Mining Software

The purchase of a single software product can represent a substantial amount of funds, and additional expenses associated with subsequent updates continue to add to the initial investment. In many software products, it is customary to have a basic program unit, which can be supplemented with additional program modules, each designed to solve specific types of engineering problems. When each of these modules must be purchased, the expenses are often difficult to absorb by academic programs that cater to specialized fields; as a result, demand is limited. For example, the Surpac software package used in geological modelling and surface mine design costs $29,000, with an annual maintenance fee of $500. Oftentimes, a solution is found by taking advantage of the educational versions of large software packages being offered at substantial discounts to the universities. Usually, professional meetings and symposia provide exhibition halls where software companies meet with university faculty members for the purpose of determining cost effective ways of providing the software to the universities. Software manufacturers are often receptive to the idea of donating their products as one method to promote their products. Regardless, if the software is either donated or sold with an educator's discount, such practices provide students with an early opportunity to work with software they will use in professional practice.

Among the assembly of commercial software incorporated into Penn State's mining engineering curriculum are:

- SURVCAD, by Carlson Software – a program to aid in the design of underground mines, geological mapping and reserve studies,
- Surpac Vision, by Surpac Software International (SSI) – a comprehensive 3-D software system for exploration and geological modelling, and mine and waste dump design,
- Talpac, by Runge Mining Inc. – simulation of a loader-truck system,
- VolvoSim, by Volvo Construction Equipment – simulation of Volvo's loader-truck system,
- DragSim, by Runge Mining Inc. – short- and long-term planning of dragline operations,
- DelPat, by DelPat – modelling of drilling and blasting operation, and
- Belt Analyst II, by Overland Conveyor Company – design of belt conveyors, ranging from the small, in-plant conveyors, to overland conveyors.

Two recent, independent surveys on mine planning software applications in Australia were conducted and included 106 surface and 59 underground metallic mines (Australia's Mining Monthly, 2000). The results of these surveys are shown in

Figure 1. Surpac by SSI, used extensively in the Penn State mining engineering curriculum, is also used abroad. With the global economy being emphasized in U.S. higher education, it is also important to note what software packages are being used worldwide.

3. Mining Engineering Example

The Mining Engineering Faculty at Penn State is committed to the development of an interactive teaching and learning environment. The goal is to insure that students play an active role in the learning process. The program strongly supports innovation in its teaching mission, use of computing, networking, and information resources to inspire and motivate students to develop a lifelong attachment to the discipline of mining engineering. State-of-the-art sophisticated computer facilities and professional software packages are made available in support of teaching and learning. As a result, the program has made a commitment, and secured funding to maintain these up-to-date software packages.

One teaching technique that is popular with engineering educators is to incorporate hands-on projects into the various engineering courses (Reagan & Sheppard, 1996). Penn State's mining-related projects are enhanced through the use of professional software within the following design-related courses: Mine Materials Handling Systems (MNG 404), Surface Mining Systems and Design (MNG 441), Mining Engineering Project (MNG 451W), and Aggregates Production (MINE 471).

As an example of how to train students in the use of professional software, MNG 441 students follow a two-step process. The first step includes a one-hour-per-week lecture session where the students are provided the theoretical background necessary to understand the basic principles and processes incorporated within the software. The second step includes a three-hour-per-week laboratory session. This involves instruction on how to use the software, the rationale behind its organization, and its arrangement, including input, run, validation, and output.

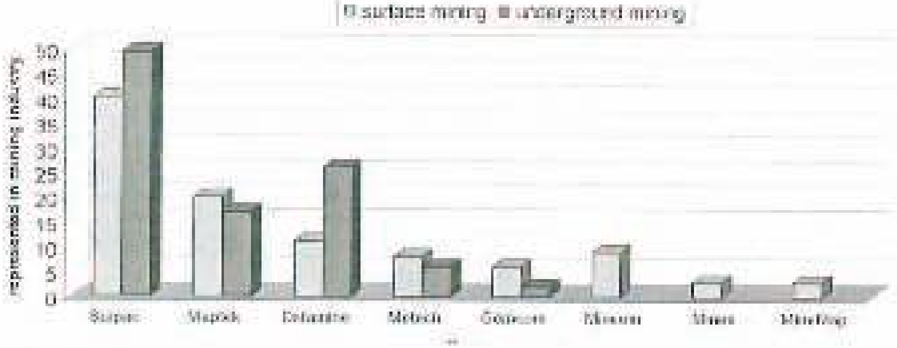

Figure 1. Application of professional mining software by the metallic mining industry in Australia.

The students use the department's computerized lab, which is equipped with a sufficient number of software licenses to enable each of them to follow and repeat instructions provided by the faculty. At the end of each lab session, the students are asked to repeat the procedure for a particular problem type until they feel confident that they understand the application. The task of the faculty is to provide a structured learning process for the students, so that they can begin to use the software early in the course, and are able to perform design tasks relatively quickly. This process is also needed because output must be analysed and interpreted in a clear, concise, and meaningful fashion.

To take advantage of the 3-D capabilities of software for orebody analysis and mine design, animated materials in the form of standard Audio Video Interleave (AVI) video files have been developed for MNG 441. The resulting files are small and highly compressed, and include the detailed, full-motion, on-screen activity of the instructor's computer-based instructions. Also, all on-screen images, including pop-up menus, menu selections, pop-up windows, layered windows, message boxes, and cursor movements are recorded. Advanced options are incorporated into the designs to enable students to pause, branch, or stop for further remediation, exploration, or enhancement opportunities. As a result, more than 1,000 templates were constructed in order to motivate the students in the learning process. Instead of sending a hard copy 200-page static tutorial to the students, the same material is sent using dynamic demonstrations, thus stimulating their involvement. These real-time videos are located on a departmental server, making them accessible through the Intranet. Such files can be viewed with the widely distributed Windows Media Player or RealNetworks RealPlayer software.

Using the Surpac software system, MNG 441 students are exposed to database creation for exploration data storage, drill hole representation, interpretation of geological properties, orebody representation by block and stratigraphic modelling, digital terrain modelling and contouring, design of surface mine and waste dump geometry by using string and Digital Terrain Models (DTM), design of drilling and blasting patterns, production grade control, and cut and fill volumes, and production scheduling. Figure 2 shows examples of copper, iron, and stone surface mines, as well as a waste dump, designed by students.

The Talpac software system is used for production and economic evaluation of loading and haulage equipment. The students are taught how to set material properties, establish rosters, appropriately select loading and haulage equipment, and to define the haulage cycle. Production, economic, environmental, and safety evaluations are performed using either a deterministic or a stochastic approach. Incremental analysis is also introduced in order to evaluate the system's performance in various stages of mine development. Figure 3 shows an example of a student's work on the simulation of a loader-truck system.

Short- and long-term planning of dragline operations are performed using the DragSim software package. This graphical and analytical tool has been used to introduce the students to a simulation of waste removal by a dragline, a determination of productivity, volumes, unit and material costs, mine sequencing and volume

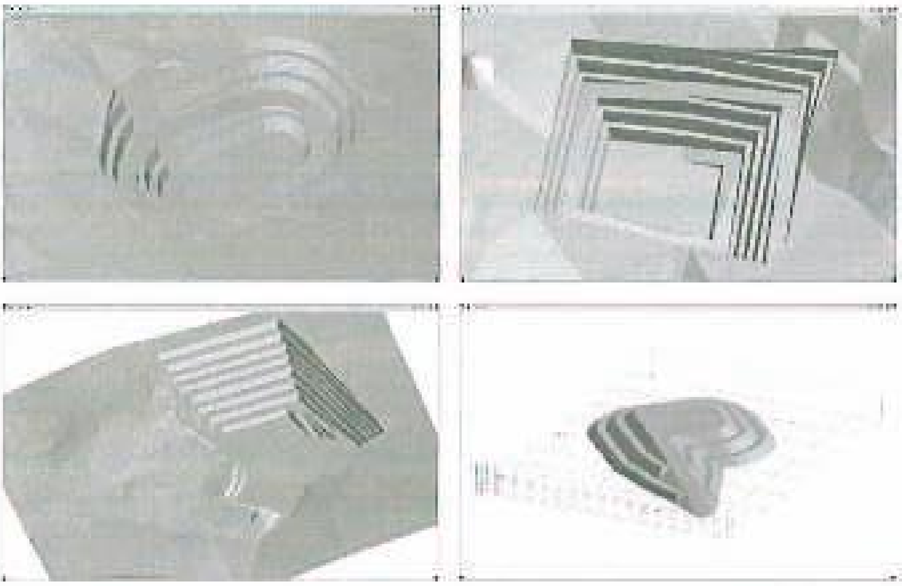

Figure 2. An example of surface mines and a waste dump designed by students.

balancing, and sensitivity analyses of selected operational and dragline parameters. Figure 4 presents an example of a student's work on dragline operation at a coal mine.

DelPat software is used to organize and analyse rock drilling and blasting systems. It includes a definition of rock properties, a selection of drilling equipment and typical arrangements, and a selection of the appropriate type of explosive. Based upon these input parameters, the students have an opportunity to analyse fragment size distribution, timing, drilling geometry, and to compare drilling and blasting costs calculated for various blasting design patterns. They are also able to determine the potential impact on the environment from a particular blasting regime. Figure 5 shows the results of a student's work on drilling and blasting design.

The Belt Analyst II software is used to simulate the haulage process by belt conveyors. In a range of applications, the students must set all required input parameters, run the simulation, perform calibration, validation, and sensitivity analyses, and compare the obtained results. The students are also required to produce e-mail-compatible output, further supporting the program goals to enhance the students' communication skills. Figure 6 shows the results of a student's work on belt conveyor design.

4. Assessment of Instructional Software

James, McInnis, and Devlin (2001) indicate that assessment needs to be consistent with the objectives of the course and what is taught and learned. The effectiveness of learning and successful completion of project assignments are largely dependent

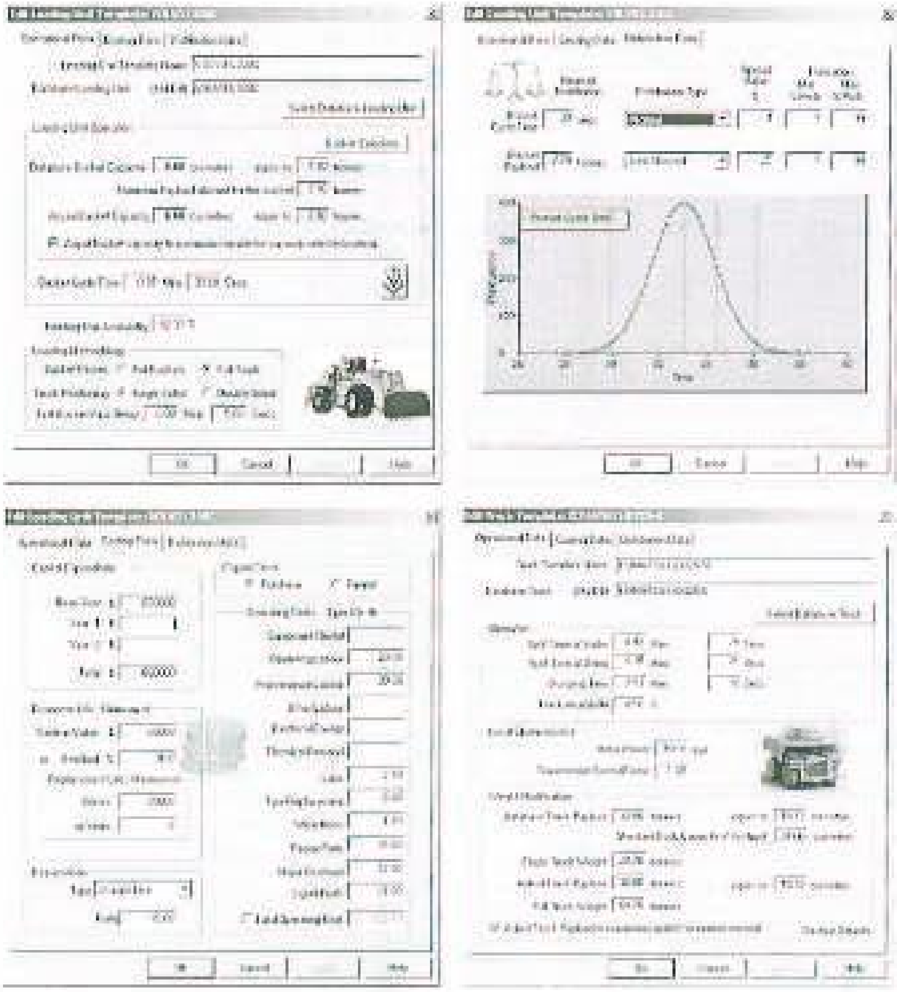

Figure 3. An example of a student's work on the design of a loader-truck system.

upon well-prepared tutorials, and worked-out examples based upon real-field data provided by mining industry representatives. Creating extensively documented tutorials is difficult and time consuming. There is a great deal of time involved in learning professional software, and most of that learning occurs outside the regularly scheduled class. Students can spend as much as 20 hours each week working on solving the problems presented in class. In addition to the interactive computer communications between the instructor and students, and among students themselves, it also has been necessary to provide hard copies and electronic versions of study materials that have been derived from both vendor's manuals and tutorials, as well as from the instructor's own experience and knowledge about a particular software package. These efforts are designed to improve learning, but the cost in time

Figure 4. An example of a student's work on the design of a coal-mine dragline operation.

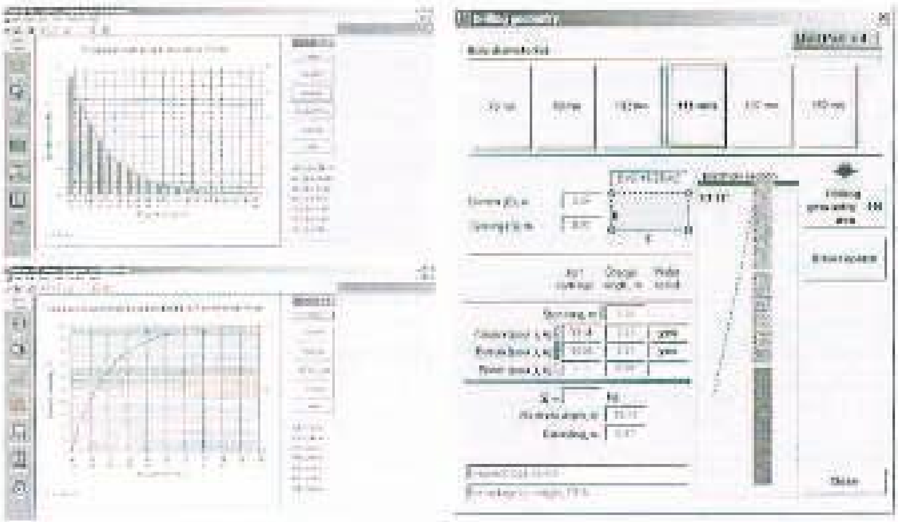

Figure 5. An example of a student's work on drilling and blasting design.

and effort cannot be minimized. Past studies have shown that the time devoted to programming effort may not always be justified when the goal is to generally describe a mine plan (Bise & Albert, 1983).

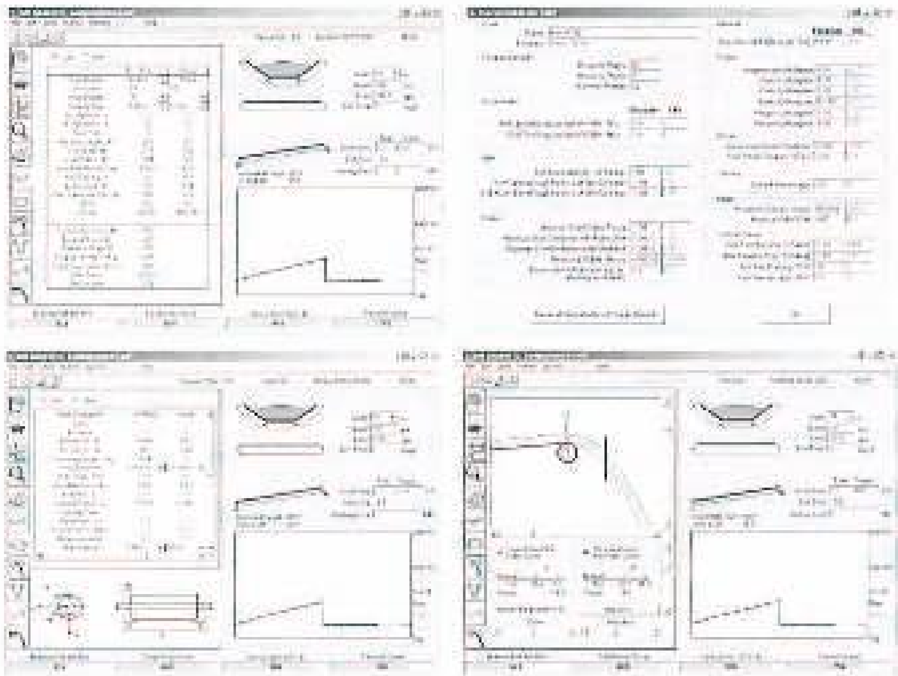

Figure 6. An example of a student's work on belt conveyor design.

Penn State students are provided with a conventional, post-course questionnaire, entitled the Student Rating of Teaching Effectiveness (SRTE). This university-produced form allows students to assess the course and instructor attributes of a course on a 0 to 7 scale; provisions are also made for open-ended, written comments. The SRTEs provide the faculty with timely responses describing the degree to which student expectations are being met. As an indication of the effectiveness of software teaching and learning, the following example can be used. Through the SRTE sheets, students were asked what they liked best about their courses. They responded that the courses have given them a valuable exposure to computer programs applicable to the mining field. Since the ratings are on a seven-point scale, scores higher than 5.0 are considered in the very good to excellent range. A recent set of SRTEs for MNG 441 were as follows:

- Rate the overall quality of this course: 6.00
- Rate the overall quality of the instructor: 5.40
- Rate the clarity of the instructor's presentations: 5.50
- Rate the instructor's willingness to help students make progress: 5.30
- Rate the instructor's skill creating a climate conducive to learning: 5.70
- Rate the adequacy of the instructor's knowledge of the subject matter: 6.20
- Rate the instructor in term of his/her preparation for class: 6.44

- Rate the organization of the course in terms of its logical arrangement of material and activities: 6.10

Obviously, the students appreciate the attributes of the course as well as the instructor.

Penn State mining engineering students complete an additional survey on each course which is used for ABET evaluation purposes. The survey lists the Mining Engineering Program Objectives and asks the students to rate the course, on a 0 to 2 scale, with regard to how well the courses satisfy the program objectives. These ratings are compared to the level to which the instructor targeted the course to meet the program objectives. Table 1 provides the students' and instructor's ratings for MNG 441. Obviously, the students rate the course as high or higher than the instructor's intention to meet the program objectives, indicating overall satisfaction with course content and delivery. Of particular significance is the high score provided by the students for Program Objective #3, which deals with computer-based technology.

However, a full assessment of the use of commercial software requires a comparison with the standard (non-computer-aided) method of content delivery. To do this, the comparison criteria include initial cost, annual renewal development time, real-time capabilities for in-class demonstrations, and capabilities for three-dimensional presentation. Table 2 summarizes a cost-benefit analysis for a surface mine design course enhanced with professional software applications, when compared to a similar course which does not include computer-aided design.

Table 1. Students' evaluation of the surface mining course, MNG 441.

Mining engineering program objectives	Instructor's rating	Students' rating (n = 12)
To deliver curriculum material that is of sufficient science and engineering rigor to ensure that students have the basis for entering the private or public sectors as mining engineers, or higher education, if they so choose.	2	2
To enable students to comprehend the interrelationships among geology, exploration, valuation, development, exploitation, and processing of mineral deposits in a coordinated manner, from the introductory mining course to capstone mine-design course.	2	2
To encourage students' use of computers and information technology, in a comprehensive manner, as it relates to engineering applications for mineral resources.	2	2
To stimulate students' awareness and appreciation for societal concerns with regard to the total environment, health and safety, sustainable development, lifelong learning, and the conservation of our natural resources.	1	1.5

Table 3. Cost-benefit analysis for a surface mine design course enhanced with professional software applications.

A	B	C	D	E	F
Standard lecture and lab	None	None	3	None	Limited
Lecture and lab enhanced with professional software	Surpac – none Talpac – none DragSim – none DelPat – $350 Belt Analyst – none VolvoSim – none	Surpac – $500 Talpac – none DragSim – none DelPat – none Belt Analyst – none VolvoSim – none	Initially: 2 for lecture organization, and 3 for the tutorial development, and application of field data for a total of 5 Upgrades: less than 0.25	Yes	Yes

A – Method of Delivery for MNG 441
B – Initial Cost
C – Cost of Annual Renewal
D – Course Preparation Time (hours per contact hour)
E – In-Class Real-Time Capabilities
F – Three-Dimensional (3-D) Presentation of Ore Bodies and Mining Systems

A close inspection of Table 2 reveals that the most widely used software is available to educators for a minimal amount of time. Obviously, the initial preparation of tutorials using software (5 hours per contact hour) requires more time than the standard lecture and lab format (3 hours per contact hour). However, annual updates of the material require less than 15 minutes per contact hour.

The true advantage to be gained using this approach is what can be done in the classroom. For example, it would take one hour (a homework assignment) for a student to do a hand calculation of a coal-reserve estimation utilizing the data from 24 drillholes; that same calculation, in class with a laptop computer and a projection system for class participation, would take one minute. Clearly, the ability for an instructor to perform sensitivity analysis in a real-time setting greatly adds to the educational experience, at minimal cost and limited, additional increase in preparation time.

5. Summary and Conclusions

Professional software enhances the understanding of how mining works, and students should be educated and skilled to use these tools. The application of professional software in the teaching and learning process enables students to acquire skills in computer-based problem solving, computer graphics, and CAD techniques. It also provides students with the opportunity to evaluate their results in an analytical and graphical fashion, and to effectively communicate their thoughts on engineering solutions, both individually and in a team environment. Additional outcomes include the development of skills to optimize mining engineering units and systems to meet desired production and costs requirements.

One other aspect that is significant relates to the employment potential of mining engineering graduates who possess understanding of modern mining-related software packages. It has been our observation that a recently employed mining engineer with knowledge of modern software packages can produce results comparable to an independent consultant at less than 25% of the cost. Clearly, companies will find it more cost-effective to do this work in-house with properly trained graduates.

In conclusion, mining engineering education in the 21st century emphasizes active learning on the part of the students, group problem solving, and a global perspective of the industry. Even though most mining engineering classes are small, these goals can still be met through the effective use of computer technology and software, coupled with real-time discussion and problem solving. In the future, the web-based e-learning technologies will become the primary choice of delivery for teaching and learning of professional mining software. These technologies will be fully appreciated when flexibility is needed, and the challenges of distance-learning will have to be addressed in a format to maximize accessibility (Curtin University of Technology, 2003; Golosinski, 2002; Thomas et al., 2003). Clearly, progressive mining-engineering educational programs must commit to using professional software in their courses.

Acknowledgments

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