Enhancing Civil and Construction Engineering Education through the use of a Web-based Collaborative Simulation

Thomas Korman
California Polytechnic State University

Abstract

Simulations and learning games create real-world experiences to provide the opportunity to engage, have fun, and truly learn. Many have been designed to meet specific learning goals, i.e. sharing case studies to demonstrating very complex situations. The practice of civil and construction involves being able to make decision to balance time, cost, quality, resources, and identifying and solving a variety of issues. As the millennium generation enters the higher education system many have spent countless hours playing computer games as they have in the classroom during their lifetime; therefore, it is a natural transition that our learning environments begin to use techniques from the gaming world. The skills required of today's construction engineers are a combination of technical knowledge and management skills. This paper describes the development of web-based simulation designed and developed at California Polytechnic State University, San Luis Obispo to educate civil and construction engineering students.

Introduction and Background

Experiential learning is learning through reflection on doing, which is often contrasted with didactic learning. Experiential learning is related to, but not synonymous with, experiential education, action learning, adventure learning, free choice learning, cooperative learning, and service learning. While there are relationships and connections between all these theories of education, importantly they are also separate terms with separate meanings.

Experiential learning focuses on the learning process for the individual (unlike experiential education, which focuses on the transactive process between teacher and learner). An example of experiential learning is going to the zoo and learning through observation and interaction with the zoo environment, as opposed to reading about animals from a book. Thus, one makes discoveries and experiments with knowledge firsthand, instead of hearing or reading about others' experiences.

Experiential learning requires no teacher and relates solely to the meaning making process of the individual's direct experience. However, though the gaining of knowledge is an inherent process that occurs naturally, for a genuine learning experience to occur, there must exist certain elements. According to David A. Kolb, an American educational theorist, knowledge is continuously gained through both personal and environmental experiences. He states that in order to gain genuine knowledge from an experience, certain abilities are required:

- the learner must be willing to be actively involved in the experience;
- the learner must be able to reflect on the experience;
- the learner must possess and use analytical skills to conceptualize the experience; and
- the learner must possess decision making and problem solving skills in order to use the new ideas gained from the experience.

COnstruction INdustry Simulation (COINS) – An educational gaming simulation for Construction Engineering

Construction Industry Simulation (COINS) is a computer simulation built to simulate the business environment for a construction company. The players, participants, play the role of contractors, competing in a market with variable demand for construction work. The simulation immerses students into the day-to-day operations of a construction company, requiring them to management specific aspects of the company with the goal of procuring and managing construction work in terms of its planning, scheduling, and resource allocation. Students have a choice between commercial construction company, a heavy construction company, or a company that does both. Players are required to set up a complete business strategy including the following tasks:

- examine available information
- determine the best portfolio of jobs to bid on
- create strategies to improve bonding limits
- set strategies to create negotiated work
- develop bid prices for desired jobs
- monitor their financial position as work progresses
- monitor and create strategies to improve company's appraisal metrics
- choose and modify their construction methods to meet due dates and reduce costs
- interpret their competitors' strategies
- respond to changing conditions and situations proposed to the company and driven by the decisions and actions of the company

Commercial Building Projects	Heavy Civil Projects
• Apartment buildings • school buildings • office buildings • hospital buildings • industrial plants	• highways • bridges • site development • mass excavation • underground utilities

Each period the simulation generates a list of jobs available for bidding and creates an Estimated Time and Cost Report for each job. Using the this information, each company must decide which jobs to bid on, the bid price, and which of the five methods to use for each of the activities. All jobs will have up to nine activities (Both Heavy and Commercial). These activities are:

Commercial Building Projects	Heavy Civil Projects

• Excavation • Foundation • Basement • Framing • Closure Roof • Siding • Finishing • Mechanical and Electrical	• Clear and Grub • Rough Grading • Excavation • Underground piping • Concrete (Form and Place) • Backfill and Compaction • Aggregate Base • Paving • Finish Grading

Every activity has five (5) different construction methods that vary in time and cost. The fifth method is generally use of a subcontractor. All five methods of activity #9 (Mechanical and Electrical) are generally subcontracted. The Estimated Time and Cost Report gives labor and material costs and the amount of time required for every activity using each of the five methods. Heavy construction bids are generally unit price bids while commercial bids are lump sum.

Project Planning and Design Phase

Students begin the simulation by being presented with a list of potential projects to review. Considering market conditions, student teams proceed by selecting a project to plan and then designing a project control system for the project. This is accomplished by selecting methods for each project activity and balancing the schedule and cost considerations. In Phase 1, students compete against their peers as well as the simulation's virtual companies for award of the project. Award of projects is based on the team's accuracy and proximity to the simulation's internal estimate. Teams that are not initially awarded a project for their efforts must continue with the simulation, refining their plans, until their plans are awarded a project. Thus, the COINS simulation enables students to learn from their mistakes.

Construction Engineering Phase

When a student team is awarded a project, they enter the Construction Engineering Phase. In Phase 2 student teams must manage their project by monitoring and controlling the project activities, analyzing the schedule and costs in reference to the methods to the activities they selected for each activity. Throughout the duration of their project, students are presented with real-life scenarios which they must respond to, thus measuring, testing, and validating the design of the project control system. Therefore, students are able to utilize their knowledge and hone their skills at controlling the process through modifying their project control system. The simulation provides feedback to the students which they then can use to continuously improve their model throughout the duration of the simulation.

Project Closeout Phase

The Project Closeout Phase begins after students have completed each activity for their virtual project. They have the opportunity to evaluate their performance using several predefined metrics, including Schedule Variance, Cost Variance, Cost Performance Index, and Schedule Performance Index.

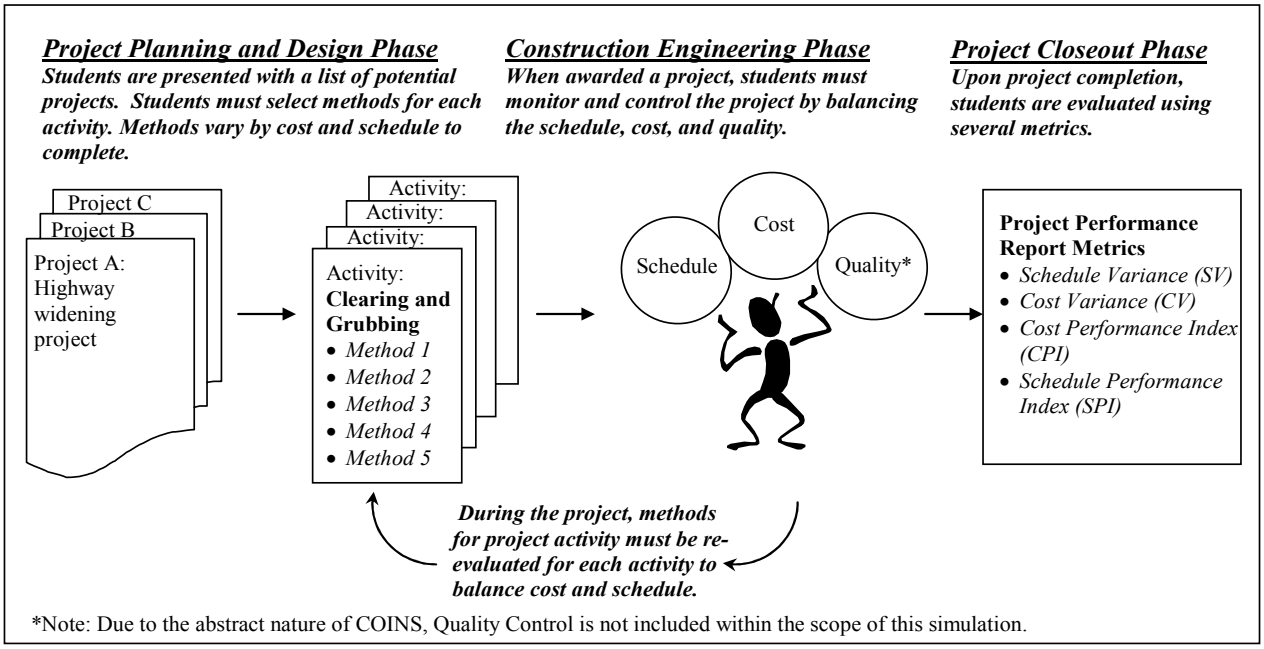

Figure 1 – Project Phases

As mention above, one of the first activities for the students is to determine what positions will make up their main office overhead. This is reevaluated each period, and hire/fire activity is performed by the team. A report is given to the company telling them how they are handling their personnel and it's requirements. Work scheduling is very important in the selection of the methods so projects can be completed by the contractual deadlines, and the costs reduced as much as possible. Each bid price submitted should cover all the firm's direct and indirect job expenses, its main office overhead costs, and the desired profit. At the end of each period the simulation will determine which company is awarded each available project. The lowest bid will not necessarily win since the computer takes into account several other factors:

- Is the firm's cash-on-hand adequate to provide enough liquidity with regard to the bid price?
- Is the bid price below a minimum amount, computed by the program? If so, then the bid will be disregarded as irresponsible and be rejected.
- Is the bid price higher than the unknown contractors, the presence of this simulated company assures a competitive, uncertain environment with realistic bid prices.
- Is the firm within it bond limits?

Companies must monitor their financial situations as the game progresses, forecasting and completing progress payments, and potential needs for loans. In any period, participants have the option to ask for information on weather forecasts, material prices, labor and material availability, and market projections. These requests for consulting services have a cost and are charged against the firm's financial account. Using the information obtained from these reports, companies can determine the best strategy to proceed for each individual job.

At the end of each period, teams receive a progress report for the previous two month period, giving a statement of the firm's work progress on each of its jobs during that time. It shows the

amount of work completed as well as the expenses incurred for each activity in every one of the company's projects. The amount of work completed during a period depends not only on the methods selected for the various activities, but also on uncertainty factors during that time such as the weather conditions, labor availability, and the fluctuating cost of materials.

An end-of-period financial report is also provided to the participants showing the expenses incurred during that period. It lists amounts spent on direct construction services, bidding costs, delay fines, taxes incurred, and interest on borrowed money. It also shows payments to the contractor by the owner according to the payment requests and gives total cash-on-hand at the end of the period. Each firm may at any time apply for a loan to improve its financial situation. Loans granted are amortized over a one year time period. Changes in company ratios are also logged along with changes to the company's appraisal metrics.

- Financial Liquidity
- Financial Success
- Responsibility
- Pace
- Ethics
- Name Recognition

At the end of a period, the firms examine their Progress Reports and decide on the effectiveness of the methods chosen for the various work activities. If they wish, they may change them and specify different methods for the following periods. The choice of methods allows companies to utilize slower but cheaper methods if they fear budget overruns, or faster but more expensive methods if meeting contractual deadlines is the main concern. In addition, overtime may be used to speed up certain activities, greatly increasing the labor costs. Firm must be concerned with the amount of liquidated damages on each project as they vary from project to project.

At the conclusion of the simulation, the program provides each participating company with a final report, forecasting the expected results of any on-going projects or their position at that point in time. It also shows the final total worth of the firm. Teams should consider maximization of profit as one of their main objective, and one of the primary criteria used to evaluate each firm's performance. As the simulation progresses, evaluations of company ratio, and appraisal metrics can be used to determine successful completion of the simulation.

Use of the Simulation

At Cal Poly, COINS has been used in several courses including:

- Professional Practice
- Construction Estimating
- Construction Accounting
- Management of the Construction Firm
- Business Practices

During the 2005/2006 academic year, the simulation was used for regional competition between multiple universities in the Associated Schools of Construction Regional 6 and 7 Student Competition.

Most recently, in November 2009, universities from the Czech Technical University (CTU) - Prague, Czech Republic, Auburn University – Alabama, California State University, Fresno - California, Illinois State University - Illinois, Boise State University - Idaho, Western Carolina University - North Carolina, and Washington State University – Washington, participated in an international competition. Competition Results were evaluated in three categories: Highest Retained Earning - received the highest profit, Highest Appraisal Metrics - the best valuation metrics and third, Most Awarded Projects - the company with the most awarded projects.

Most recently, between September 2012 and December 2012, the authors sponsored an international game where universities from the Czech Technical University (CTU) - Prague, Czech Republic, California State University, Fresno, California Polytechnic State University, San Luis Obispo, and Northwestern University, Illinois State University completed against each other. The competition concluded with an assessment of student learning described below.

Assessment of Student Learning

The simulation has a built-in grading module that can be used to obtain statistic on the various companies for comparison or to use in the classroom for grading the simulation. Each faculty can have their own method of grading. The following on faculty used a criteria for assessing participation and student learning:

- Number of jobs bid
- Minus the jobs rejected (i.e., not enough bonding capacity, substantially low cost estimate, etc.)
- Number of times the number jobs you are the lowest cost
- Number of times the company retained earnings
- Company's appraisal metrics

Using the seven principles of good practice as an evaluation metric, the COINS system performs well. It encourages contact between students and faculty by encouraging frequent student-faculty contact in and out of classes, which is an important factor in student motivation and involvement. Faculty concern helps students get through rough times and keep on working. Knowing a few faculty members well enhances students' intellectual commitment and encourages them to think about their own values and future plans. It develops reciprocity and cooperation among students. When using the COINS systems, learning is enhanced when it is more like a team effort than a solo race. Good learning, like good work, is collaborative and social, not competitive and isolated. Working with others often increases involvement in learning. Sharing one's own ideas and responding to others' reactions sharpens thinking and deepens understanding. COINS encourages active learning. Learning is not a spectator sport. Students do not learn much just by sitting in classes listening to teachers, memorizing pre-packaged assignments, and spitting out answers. They must talk about what they are learning, write about it, relate it to past experiences and apply it to their daily lives. They must make what

they learn part of themselves. COINS gives prompt feedback. Knowing what you know and don't know focuses learning. Students need appropriate feedback on performance to benefit from courses. When getting started, students need help in assessing existing knowledge and competence. In classes, students need frequent opportunities to perform and receive suggestions for improvement. At various points during college, and at the end, students need chances to reflect on what they have learned, what they still need to know, and how to assess themselves. The use of COINS emphasizes time on task. The time plus energy equals learning. There is no substitute for time on task. Learning to use one's time well is critical for students and professionals alike. Students need help in learning effective time management. Allocating realistic amounts of time means effective learning for students and effective teaching for faculty. How an institution defines time expectations for students, faculty, administrators, and other professional staff can establish the basis of high performance for all. Use of COINS communicates high expectations. Expect more and you will get more. High expectations are important for everyone -- for the poorly prepared, for those unwilling to exert themselves, and for the bright and well-motivated. Expecting students to perform well becomes a self-fulfilling prophecy when teachers and institutions hold high expectations for themselves and make extra efforts. COINS respects diverse talents and ways of learning. There are many roads to learning. People bring different talents and styles of learning to college. Brilliant students in the seminar room may be all thumbs in the lab or art studio. Students rich in hands-on experience may not do so well with theory. Students need the opportunity to show their talents and learn in ways that work for them. Then they can be pushed to learn in new ways that do not come so easily.

Discussion and Recommendations for Future Implementations

Some early recommendations during the first stage the simulations development included: creating learning objectives, creating an outline or direction, and to create modules. Even the simple simulations generally cannot be completed during the first development stage. Having a framework of different modules and what each might accomplish is critical to success and the development process. Most times having a group to develop this direction and the different modules that might be needed is a key to creating complex and broad simulations.

To assist in the development of COINS, the developers have developed an Industry Advisory Board (IAB) from the construction industry as well as a working group of educators to continue the development and ideas for changes. Because of the idea of module development COINS can turn on and off some of its modules, making it a better fit in different classes. For example, estimating can be turned to an automatic mode which in a construction accounting class helps the student focus on accounting and not on the estimating itself which can be very time consuming and complex. Periods can move much quicker giving the students more accounting to analyze and in a shorter time in which they can see the changes that occur within a company without being bogged down in the estimating/procurement of work. Billing can be turned on to auto mode and additional projects can be added to each team to create additional project or backlog. The game play between commercial and heavy/civil construction is also modulized so a faculty can play only commercial, heavy/civil or both can be played in one game. Future additions are also planned as modules, i.e. personnel additions, case studies, and wide use of equipment management.

Bibliography

[1] Bonds, C.; Cox, C. III; and Gantt-Bonds, L. "Curriculum Wholeness through Synergistic Teaching." The Clearing House 66/4 (1993): 252-254.
[2] Bonwell, C.C. and Eison, J.A. Active Learning: Creating Excitement in the Classroom. ASHE-ERIC Higher Education Report No. 1, George Washington University, 1991.
[3] Felder, R.M. and Brent, R. Cooperative Learning in Technical Courses: Procedures, Pitfalls, and Payoffs. ERIC Document Reproduction Service Report ED 377038, 1994.
[4] Johnston, Hal, Borland, Jim, and Craig, K., " Building Industry Game (B.I.G.) A Computer Simulation for Construction Management," ASC Proceedings of the 39th Annual Conference, pp 79-90. [Online]. Available: http://ascpro0.ascweb.org/archives/cd/2003/2003pro/2003/Johnston03.htm
[5] Korman, Thomas M., and Johnston, Hal A., "Development of Use of a Virtual Construction Company Simulation System for Education", FECS'12 The 2012 International Conference on Frontiers in Education: Computer Science and Computer Engineering, WORLDCOMP'12 The 2012 World Congress in Computer Science, Computer Engineering, and Applied Computing, Las Vegas, NV. July 2012.
[6] Korman, Thomas M., "Design and Implementation of Experiential Learning Exercises for Commercial Building Construction Education" Proceedings of the 2012 ASEE PSW Section Conference, Cal Poly - San Luis Obispo, CA, April 2012.
[7] Korman, Thomas, and Johnston, Hal, "Enhancing Construction Engineering and Management Education using a COnstruction INdustry Simulation (COINS)", 2011 ASCE International Workshop on Computing in Civil Engineering: June 19-22, 2011, Miami, FL, USA.
[8] Korman, Thomas M. and Johnston, Hal "Enhancing Construction Management Education though the use of a Virtual Construction Company Simulation System, " The 2nd International Symposium on Engineering Education and Educational Technologies: EEET 2010 in the context of The 3rd International Multi-Conference on Engineering and Technological Innovation: IMETI 2010, Orlando, FL, July 2010
[9] Lacey Duckworth, Dr. Tulio Sulbaran, Dr. Andrew Strelzoff, Professor Hal Johnston, "Application of a Communication Protocol Methodology to Embed a Collaborative Virtual Reality Environment in Building Industry Game" The 2011 International Conference on Software Engineering Research and Practice