Enhancing Construction Management Education through the use of a Virtual Construction Company Simulation System

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ABSTRACT
Simulations and learning games use technology to 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. Gaming is not new to higher education but in the past was done in a very narrow vein and because of the complexity and development time required to produce them. Most have not been robust enough to engage students. Managing 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 many 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 management personnel are a combination of management skills and technical knowledge. This paper describes the development of gaming system designed and developed at California Polytechnic State University, San Luis Obispo to educate construction management students.

Keywords: Simulation, Gaming, Construction Education, Open Source, Construction Industry Simulation, Building Industry Game

1. INTRODUCTION AND BACKGROUND
Simulations have been used to help people learn for decades in pilot education, firefighting, driving, etc. Current on-line simulations run the gamut from complicated mathematical models to interpersonal skills development tools. Some simulations are all online while others mix in real-world in-person rehearsals that follow your time online.

The use of performance-based simulation learning tools to educate has been growing rapidly due to the decisive success rates of specialized, interactive content that teaches leaders high-level business acumen in a real-world, risk-free setting. A recent survey revealed that "by 2020 the use of simulations will quadruple.... Simulations provide a parallel universe in which employees hone their skills... Innovative companies have realized this, and others will follow [15]." Companies like Accenture, IBM, SimuLearn and OutStart have expanded performance testing from mildly interactive e-learning programs into full-fledged training development software and content-authoring tools, which may be customized to fit any organization’s needs.

2. OVERVIEW OF EXPERIENTIAL LEARNING
Much of the basis for simulation design has historically been rooted in experiential learning. Human beings absorb information through the senses, yet humans ultimately learn by doing. For example, humans watch and listen to others, then try doing things on their own. This sparks interest and generates motivation to self-discover. Humans master new skills by actively participating in events and reflecting on what they experienced. Kurt Lewin wrote that little substantive learning takes place without involving something of all three aspects [7]. Learning also involves feeling things about the concepts (emotions) and doing something (action). These elements need not be distinctive; they can be, and often are, integrated.

In the book Experiential Learning, David Kolb describes learning as a four-step process [4]. He identifies the steps as first watching, second thinking (mind), third feeling (emotion), and forth doing (muscle). He draws primarily on the works of Dewey (who emphasized the need for learning to be grounded in experience), Lewin (who stressed the importance of a people being active in learning), and Jean Piaget, who described intelligence as the result of the interaction of the person and the environment [5].

Kolb wrote that learners have immediate concrete experiences that allow humans to reflect on new experience from different perspectives [5]. From these reflective observations, humans engage in abstract conceptualization, creating generalizations or principles that integrate observations into sound theories. Finally, humans use these generalizations or theories as guides to further action. Active experimentation allows humans to test what was learned in new and more complex situations. The result is another concrete experience, but this time at a more complex level.

To be effective learners, humans must perceive information, reflect on how it will impact some aspect of their lives, compare how it fits into their own experiences, and think about how this information offers new ways for them to act. Learning requires...
more than seeing, hearing, moving, or touching to learn. Humans integrate what is sensed and think with what is felt [5]. Without that integration, humans are just passive participants and passive learning alone does not engage the higher brain functions or stimulate the senses to the point where humans integrate lessons into existing schemes.

Simulations provide a mechanism for active learning that results in longer-term recall, synthesis, and problem-solving skills than learning by hearing, reading, or watching. Simulations assist the learning environment to move from a learning-by-telling model and even learning-by-observing (as in the case-method) to a learning-by-doing model, from passivity to activity, and to extrapolate experiences to application [12].

3. DEVELOPMENT OF THE COINS SYSTEM

At California Polytechnic State University, San Luis Obispo (Cal Poly), a construction business simulation named Construction Industry Simulation (COINS) has been developed to enhance student learning in construction management departments. Using COINS students are placed in teams to manage a construction company. Their virtual company comes complete with dynamic financial statements, injury illness and prevention (IIP) programs, continuous improvement programs (CIP), an employee handbook business plan, personnel descriptions for all employees, company backlog of work if wanted history, etc. Using COINS, student teams make business decisions over time and the simulation provides a framework for company accounting, project management, procurement of work, etc.

COINS originated out of an idea by Hal Johnston, Professor in Construction Management Department and Emeritus Faculty Jim Borland at Cal Poly in San Luis Obispo, California. The first version of COINS was known as Building Industry Game (BIG). The BIG simulation game focused on the commercial building sector of the construction industry. BIG had a built-in an estimating and scheduling simulation and some accounting, which students used to emulate managing a commercial building contractor. The origins of BIG began with Glenn Sears, Professor Emeritus, of the University of New Mexico. Professor Johnston and Borland were granted permission from Professor Sears to write, modify, convert BIG to C++. The idea that BIG could become something much larger and more robust game came about with collaboration between Hal Johnston, Professors in Construction Management Department and Jim Borland at Cal Poly in San Luis Obispo, California. It was their intent that BIG would become part of a larger integrated construction company simulation that incorporated more sectors of the construction industry. The name Construction Industry Simulation or COINS incorporates that concept. Using BIG as template, COINS BIG/COINS was developed into a web based simulation written with a in JAVA front-end and using PostgreSQL database by the Cal Poly Faculty Multimedia Group under the direction of Professors Hal Johnston and Jim Borland. BIG/COINS was developed using open source software and continues to be open source in nature. The simulation uses a dynamic accounting engine, as a core to it's many other parts and modules.

COINS is not just an estimating game; the developers goal was to produce a simulation that included bid strategy, project management, construction accounting, strategy, etc. Parameters that can be set by the instructor include the following:

- Method parameters for each activity type
- Size statistics for each job type
- Network dependencies for each job type
- Number of jobs available
- Material cost index
- Consulting costs
- Liquidated damages parameters
- Computer controlled contractor parameters
- Negotiation game parameters
- Personnel parameters
- Other miscellaneous game parameters

Future changes are planned for COINS simulation in effort to create a more robust simulation. These include:

- Equipment management
- Unit price bidding
- Unit price billing
- Equipment parameters
- Equipment as a cost item
- Dynamic depreciation
- Equipment feedback loop
- Personnel resumes and interview
- Case studies

Considering the market place has both private projects in which contracts are most frequently negotiated and non-bonded and public projects where contracts are typically bid and must be bonded. COINS contains both. After some success, a company may be put on select bidders lists and even move onto being considered for negotiated projects.

For the commercial building construction sector, each project is made up of nine activities, which are included in a projects schedule. These are:

- Excavation
- Foundation
- Basement
- Framing
- Closure
- Roofing
- Siding
- Finishing
- Mechanical, electrical, and plumbing

For the heavy civil construction sector, each project is made up of nine activities, which are included in a projects schedule. These are:

- Clear and grubbing
- Rough grading
- Excavation
- Underground utilities (water, sewer, storm drain)
- Concrete placing and finishing
- Backfilling and compaction
- Aggregate placement and compaction
- Paving
- Finish grade

For each activity, there are five (5) different construction methods to select from; therefore, the cost and overall schedule is determined by the methods picked for each activity.

The following types of commercial building construction projects (public and private) are included in the simulation:

- Case studies
• Multi-family housing
• Educational facilities
• Hospitals and medical office buildings
• Commercial office buildings
• Industrial manufacturing facilities

The following types of heavy civil construction projects (public and private) are included in the simulation:
• Highways projects
• Bridges
• Residential site development
• Mass excavation
• Underground utilities

4. OVERVIEW OF GAME PLAY

COINS allows the game administrator (instructor) to place the player or team into a situation or incident that could require a quick short term solution or possibly a long term change in the company. Situations also take the form of cases that require ongoing management by the player or team over an extended period of time. The game can simulate the month-to-month problems, issues and decisions required to manage a construction company successfully.

Student teams are able to hire virtual staff as needed, deal with monthly problems, make choices, and experience the results of their decisions. During game play, participants gain experience and exposure to a cadre of real world scenarios, are provided with the opportunity to gain experience, learn from their mistakes, and to experience the totality of management required of the construction professional. Each team is given an equal amount of capital at the start of the game.

Time is represented as "periods," each period being two months of real-time. The period is advanced once or twice per week. Each period, new projects are available for bidding. With the increasing number of awarded contracts, companies must recruit other overhead personnel or the companies must pay large additional sums for the employment of external consultants.

Ultimately, the goal of the students during gameplay is to achieve the best possible project and company outcome by developing the ability to analyze situations, gather data and make strategic decisions between time, cost and quality - the essence of project management. Specific aspects of the game play is described below:

Personnel Management
The first order of business for game play is for students to form a multiple student team and create a company, develop a mission statement and core value statement. Student teams are given a username and password by instructor. Teams then register their team members. Each student team member plays the role of a construction firm. Teams are required to hire personnel, creating main office overhead, i.e. President, Marketing Director, Estimator, Student Intern, Scheduler, Accountant, etc. They are permitted to change personnel, as they need either for growth or other reasons.

Business Development and Work Procurement
Teams are given quantities, expected production, and costs for each activity on every job available for bid. The student teams must decide which jobs to bid on, select a method for each activity, determine their direct cost, then settle on a bid price by adding jobsite indirect, contingency, mark-ups and desired profit. The simulation is also able to internally generate bids on every job to keep the players cost estimates and bids within reason. As the period advances, the computer evaluates bids on each project and awards contracts to successful bidders. Players evaluate the results and attempt to interpret their competitor’s strategies as the game progresses. Construction bids are rejected if they fall below a minimum amount (calculated by the computer). In order to bid on a project, student teams must have cash-on-hand, along with other strong financial indicators. These items help the computer set individual project size limits for bonding purposes, which is at least 5% of their bid amount. Companies may not be overloaded with too many other jobs and therefore, all companies have a work in progress bonding limit that may not be exceeded also.

Project Management
Players must monitor their financial position as work progresses, and bill for their progress payments. Also, teams must create strategies to improve their bonding limits. A record of successful projects creates an opportunity to obtain negotiated work. At the end of every period, each team receives a:
• Progress Report
• Complete Dynamic Financial Report
• Analysis Report of the work accomplished, and
• financial result to date.

The amount of work completed during a period depends on: the production rate for the work packages selected on each activity and the uncertainty factors, including - weather conditions, labor availability, and fluctuating cost of materials.

The end-of-period financial reports show expenses incurred for:
• Direct construction costs
• Bidding costs
• Consulting services
• Liquidated damages, and
• Interest on borrowed money

Student teams must monitor their financial position as work progresses, and bill for their progress payments. Also, teams must create strategies to improve their bonding limits. A record of successful projects creates an opportunity to obtain negotiated work. Changes in company’s financial position will change ratios and are also logged along with changes to the company’s appraisal metrics:
• Financial liquidity
• Financial success
• Responsibility
• Pace
• Ethics
• Name recognition

As gameplay progresses, teams have the following options:
• Pay a consulting fee to receive information on weather forecasts, material prices, labor and material availability, and market projections for future periods.
• Apply for loans.
• Make a change and specify a different method for the following periods.
• Use overtime to speed up certain activities (greatly increasing the labor costs).

Each company must evaluate the projects they have, changing methods if needed, and at the very least, bill for the work they completed during that period. Billing affects cash flow and cash position on the balance sheet and potentially the company’s bonding capacity.

A financial report shows the final total worth of the firm in either case. Maximization of profit & strong financial condition are main objectives, but additional emphasis can be placed on the company appraisal metrics. At the conclusion of the gameplay, the instructor can either:

• have the simulation forecast the expected results of any on-going projects or
• use the actual results at that time.

5. USE OF THE COINS 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.

6. 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.

7. CONCLUSIONS

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 fist 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.

8. REFERENCES

When it comes to construction companies, Sundt has a serious foothold in every arena, from mining and industrial to commercial, government, and health care contracts. Working at such a large scale and with the potential impacts of, say, something like a major bridge project, Sundt has recognized virtual construction as essential to increasing productivity and minimizing risk. Enter Eric Cylwik, a virtual construction engineer who works within Sundt’s transportation group. Cylwik is a Building Information Modeling (BIM) wizard who graduated from Arizona State University.

At the same time, qualifications-based selection was working its way through the Arizona market, and Sundt hired me to create 3D visuals for a project interview. It was the best of both worlds. Disrupting the Construction Industry: A Breakdown On Startup Driven Innovation. Though the construction industry was always perceived as stable it faces numerous challenges today. The digital revolution touches construction companies, creating a massive potential for innovation in various shapes and forms. Moreover, construction software solutions give a very clear understanding of the performance of a building company by providing detailed analytics and reports through customizable dashboards. Furthermore, powerful cloud services developed specifically for this industry are equipped to store a vast amount of data gathered by drones and other digital services. Danish startup GenieBelt created a project management software for the construction industry. How are drones affecting the construction industry? Read on to find out how drones are shaping six areas of the business of building. The use of drones in job site inspection also means a drastic increase in worksite safety by eliminating numerous dangers and safety hazards. Using drones to transport goods aerially allows companies to execute difficult inspections and keep track of everything that enters and leaves the job site. It saves money and time and keeps the site secure. Construction Resource Management to Increase a Company's Profit. How Drones Will Change the Insurance Industry. Duties and Responsibilities of a Construction Safety Officer. 9 Construction Trends for 2019. How “The Internet of Things” Is Affecting the Construction Industry.