Simulation Games in Engineering Education: A State-of-the-Art Review

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ABSTRACT: Globalization and advances in information technology has prompted a need to change traditional lecture-based passive learning methodology to an active multi-sensory experiential learning methodology. This article presents a state-of-the-art review of extant applications of simulation games in engineering education. It was concluded that proper application of simulation games in engineering education would maximize the student's transferability of academic knowledge to the industry. © 2009 Wiley Periodicals, Inc. Comput Appl Eng Educ 19: 399–410, 2011; View this article online at wileyonlinelibrary.com/journal/cae; DOI 10.1002/cae.20323

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INTRODUCTION

Today's students represent the first generation to grow up with the new digital technology. Since childhood, they have experienced computers, videogames, digital music players, video cameras, cell phones, and all the other tools of the digital age. Today's average college graduates have spent less than 5,000 h of their lives reading, but over 10,000 h playing video games [1,2]. Computer games, email, Internet, cell phones, and instant messaging have become integral parts of their lives. Due to this "digital" environment and their constant interaction with it, today's students think and process information fundamentally differently from their predecessors. These "digital natives" have a limited attention span, lower tolerance for repetition, boredom of static media, and a more visual learning style than their predecessors. The demand from the industry has also changed. Today, engineers are expected to work with managers and marketing personnel. They need to have good interpersonal skills, communication abilities, and team dynamics. Unfortunately, the engineering academia has not responded to this transition and demand. This is evident from the decreasing number of students in engineering colleges, both in undergraduate and graduate programs.

Engineering subjects are highly theoretical and thereby have mainly been taught by the didactic lecture-based format accompanied by rigorous problem-solving exercises [3]. The amount of information in the engineering field is increasing at an exponential rate with many research fields emerging over the past few decades. In addition, the skills required by an engineer are so high that universities find it difficult to deliver a comprehensive curriculum in 4 years of undergraduate study [3]. The situation has worsened now as an increasing number of students take on part-time jobs in order to support themselves and settle accumulated debt. Thus, students must be well equipped to acquire an understanding of the expanding field of engineering outside of their learning environments. There is also an onus on universities to produce creative thinkers among their engineering graduates [3].

Computer simulation games, refined graphics, and multimedia can be developed to present engineering topics in ways that are not possible within the limitations of the traditional lecture format. Using animations, graphics, and an interactive environment, the instructional media can be designed to engage and stimulate students to effectively explain and illustrate course topics, and to build problem-solving skills [4]. By accounting for their success and mistakes in a simulated environment, students will be motivated to accept personal responsibility for their decisions. When using simulation tools, the role of the instructor is changed from a teacher to an enabler of the learning process [5]. Not all teachers are accustomed to this kind of change in instructional technique, and sometimes they are reluctant to adapt. The reasons include (1) unawareness of the capabilities of simulation tools, (2) difficulty in obtaining the required resources (i.e., computers and simulation software), and (3) inability of the instructor to use the latest technology.

Even though computer use is now prevalent in engineering courses, self-learning educational software in the form of interactive simulation games is rarely developed. This is because of the difficulties that exist in programming engineering concepts and theories, and the design of a suitable interface [6]. More than

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95% of engineering courses are still taught in the traditional lecture-based format. Adaptation of simulation games for engineering education remains a challenge. This article aims to present the concepts of simulation games and their applications in engineering education; thus providing some guidelines and references for researchers and educators interested in this field. The second section of this article describes simulation games and their advantages in engineering education. The third section presents a comprehensive survey of simulation games and their applications. The fourth section analyzes the current state of simulation games in engineering education. Finally, a conclusion is the drawn in the fifth section.

SIMULATION GAMES

Simulation, in its simplest definition, is just ''representation of reality or some known process/phenomenon.'' It is a mathematical or algorithmic model with appropriate set of constraints that allows predictive analysis of the system [7]. Simulations allow ''what-if'' analysis on a number of different solutions, which may not be feasible in reality. Thus, it follows a ''practice in safety'' approach to implement the optimal decisions with the required constraints. On the other hand, the purpose of a game is to capture the attention of the player by the elements of conflict, motivation to win, and a scoring metric. The player has a sense of win or loss and receives a performance index in terms of score after playing the game. The desire to improve the score drives the player to get more and more involved in the game. However, steps to make the game more interesting usually leads to distortion in the representation of reality.

In spite of the recent buzz around the field of ''simulation games,'' its exact definition remains unclear. Their applications in the field of education and training of professionals demand a precise and unambiguous definition. A simulation game is a game, which has elements like score, performance rating, conflict, and payoff, and simulates a real world situation for decision-making or alternative evaluation. These multi-sensory experiential learning tools allow the player to experience cooperation and teamwork without the risk of expensive mistakes. Simulation games follow the widely accepted ''learning by doing'' philosophy.

Simulation game-based learning is an extension of the problem-based learning paradigm, having all its inherent characteristics plus some additional advantages. Simulation game and problem-based learning are both experiential learning, collaborative, active, and learner centric approaches. In simulation game, the instructor is a facilitator of the learning process and students have the responsibility of learning as in problem-based learning. In problem-based learning, a self-assessment is conducted at the end of the problem or the learning cycle. On the other hand, simulation game has a scoring system that is the indication of one's performance. Students are motivated to maximize their score by trying alternative strategies and read more literature. This is a significant advantage over problem-based learning. Secondly, simulation games can be offered online, where a student can learn as per his or her time at any place where there is an Internet connection. Some studies have found that engineers are visual learners. Advanced graphics and multimedia may be used to capture the student's attention. This observation calls for extensive use of simulation games, especially in the light of decreasing computer hardware cost and increasing computing speeds. Thirdly, some sort of online help is provided in simulation games. Thus, a student does not have to wait for the instructor to address the difficulty. Last and the most important advantage with simulation games is that they can save a lot of clerical work for students. The student can try out various strategies and alternatives and focus on the parameter of interest, leaving the calculation and presentation work for the software. It is a more systematic and organized way of learning. The advantages of simulation games include:

- They are a method of organized experiential learning that incorporates an element of fun in the learning process.
- They help connecting theory and practice to foster student's understanding of the subject [8].
- They possess the ability to alter attitudinal positions when designed in accordance with theory [9].
- They open up dynamic participation, which should lessen resistance to accept innovative ideas and concepts [10].
- They can guide students in understanding concepts and provide students a holistic working knowledge of the subject [11].
- They give immediate feedback to the student making the interaction with the game a learning process rather than an evaluation process [12].
- They provide students an opportunity to face the consequences of the results of the decisions taken or process applied and not just be an observer [13].
- They make repetition and drill on a specific topic more enjoyable, thus allowing the student to develop proficiency in a given area [4].
- They have increasing range of difficulty to challenge the student to develop to a more advanced level of comprehension [12].
- They show greater retention over time than the traditional classroom instruction [14].

STATE-OF-THE-ART SURVEY

Organizations Involved in Simulation Games

The widespread use of computerized games started in 1960. In 1962, McKenney conducted an experiment to compare the performance of a gaming class to that of non-gaming classes using the Harvard Business Game. In this experiment, the participants in the gaming class showed a better performance. In 1967, a team from MIT developed the Logo language known as ''the language for learning'' [15]. Logo was originally designed to introduce children to programming concepts and to develop better thinking skills that could be transferred to other contexts. The first role-playing game, known as ''Adventure,'' was developed at Stanford in the 1960s. The October 1970 *Scientific American* issue described the game of LIFE, a simulation of cellular growth patterns. Today the use of simulation games in education is becoming more and more popular with the highest number of applications in the area of social sciences. It is estimated that the computer game industry has a greater budget than the world music and film industry. There are a number of professional organizations and funded project teams focusing their research on developing and validating simulation games in education.

Society for the Advancement of Simulation and Gaming in Education and Training (SAGSET), a voluntary professional

society, was formed in 1970 to improve the effectiveness and quality of learning with interactive experiential learning medium, role-play, simulation, and gaming. SAGSET encourages and supports the development of simulation gaming and other forms of active learning in all the aspects of education and training. The focus of E-GEMS project (Electronic Games for Education in Math and Science) was to design and build educational computer games, strategies, and materials to integrate game-like computer activities with other forms of classroom learning. The team consisted of students, researchers, computer scientists, and industry personnel. The Leonardo-Da-Vinci program of the European community conducted the CAESAR project (Computer Aided Education with a Simulation Approach for the Redesign of Production Processes) from 1995 to 1998. The aim of the project was to develop and distribute simulation games for vocational training with the help of universities and industrial partners. Table 1 shows a list of organizations involved in simulation games research.

Applications of Simulation Games in Education

Simulation games have been applied in various education domains. Here we briefly summarize general education applications before presenting a detailed survey of engineering education applications. Non-engineering applications include:

- *Architecture*: Agapiou [16] describes the use of an online simulation game to deliver management, practice, and law subjects to architecture students. The web-based game allows students to observe the transformation of designs into buildings with the use of the contract management process.
- *Business ethics*: Schumann et al. [17] describe a simulation game for students to experience the problems involved in making tough business decisions and the ethical issues involved.
- *Child development*: Harper [18] explains a simulation technique to teach graduate course in child development, which involves application of child development knowledge to solve a predefined problem.
- *Interviewing skills*: Rickard and Titley [19] argue that use of games in improving interviewing skills can help students identify their strengths and weaknesses. The game is an integral part of a graduate level course covering basic components of the interviewing process, hypothesis generation, and testing.
- *Laboratory management*: The goal of the simulation game is to help execute laboratory management activities ranging from determining staffing level to equipment acquisition [20]. The game also plays a vital role in training the laboratory workers at various levels.
- *Medical*: The medical field has tremendous application of simulation games because of the 'Practice in Safety' principle. The game developed by Mann et al. [21] for learning surgical management principles was modeled in Visual Basic and 3D interactive simulations. Silverman et al. [22] describes an interactive computer game HEARTSENSE for changing the behavior and improving knowledge of persons with heart disorders.
- *Physics*: Lee et al. [23] describe the ''Spectrum'' game to explain the concept of energy and its relation to light. The game was built for IBM-PC using object-oriented PASCAL. The ''Frantic Physics'' game built for the Windows operating system cover topics in mechanics, electromagnetic, optics, sound, and calculus [24]. White [25] explains the computer game to teach Newton's laws of motion to students. A simulated Newtonian environment is created where the students have to control a spaceship and carry out the required tasks during which they study the fundamentals of Newton's laws.
- *Mathematics*: The ''Tic-Tac-Toe'' game is a competitive and challenging mathematical environment for students to prepare themselves for calculus [24].

Taxonomy of simulation games application in engineering education is shown in Figure 1. A detailed survey is presented in the following subsections.

Civil Engineering. Au and Parti [26] suggested that computerized heuristic games could be used for the education of engineers and planners in the construction industry. A number of researchers [27−30] describe various simulation game models for construction management including planning and control of various construction projects. Herbsman [31] described the use of project management games emphasizing on various tasks and tradeoffs involved in the civil engineering projects. AbouRizk and Sawhney [32] developed an Internet-based Interactive Construction Management Learning System (ICMLS) using a rich graphical user interface, Virtual Reality Modeling Language (VRML), and discrete-event simulation for construction management education. Scott et al. [33] described the use and evaluation of a web-based simulation game, which uses simulation model of an earthmoving project to provide players exposure to the management and control of construction projects. The model contains many of the aspects of a real project including planning, decision-making, uncertainty, environmental variables, and financial budgets to teach planning and control to undergraduate students in construction engineering.

Electrical Engineering

Digital Signal Processing. Morrow et al. [34] developed WinDSK, a Windows 9X/NT (written in C++) application to illustrate various concepts in digital signal processing using audio signals. WinDSK provides a basic DSK (Digital signal processing Starter Kit) control set, an EEPROM programming utility and a real-time debugging tool.

Power Electronics. Swiss Federal Institute of Technology Zurich has developed a software tool ''iPES—Interactive Power Electronics Seminar'' for teaching power electronics circuits and electrical machines [35]. The software, built with HTML and Java Applets, can be accessed by students online with a standard web browser on any operating system. Translations in various other languages, such as German and Chinese, are also available.

Computer Engineering

Digital Logic. Kharma et al. [11] developed the MagicBlocks game, which can be used in conjunction with instructor-led lecture. MagicBlocks allows the user to build elaborate digital logic constructions from simple logic blocks. The authors conclude that a game is an effective means to gain a holistic working knowledge and fundamental concepts involved. El-Hajj and Kabalan [36] describe an innovative method to simulate

Table 1 Simulation Games Research Organizations

Organization	Website	Research activities
Association for Business Simulation and Experiential Learning (ABSEL)	www.absel.org	Business simulations and experiential exercises Effective teaching Assessment of training methods Learning theory Simulation research Multimedia and advanced technologies Support and promote the academic study of digital games
Digital Games Research Association (DiGRA)	www.digra.org	Social, political and ethical issues related to digital games and gaming Interactive media, gaming cultures and globalization processes
International Simulation and Gaming Association (ISAGA)	www.isaga.info	Enhance the development and application of simulation and gaming methodologies Encourage a wider use of simulation and gaming methodologies Facilitate communication among specialists of simulation and gaming Exchange information about and experience of simulation and gaming methodologies Encourage interchange between the profession of simulation and gaming and other professional areas and disciplines
Simulation and Gaming Association—The Netherlands (SAGANET)	www.saganet.nl	SAGANET is the Netherlands section of ISAGA (International Simulation and Gaming Association)
Società Italiana Giochi di Simulazione (SIGIS)	www.isaga.info	SIGIS is the Italian section of ISAGA (International Simulation and Gaming Association)
Japan Association of Simulation and Gaming (JASAG)	www.jasag.org	Creation and application of new technologies in teaching and learning
North American Simulation and Gaming Association (NASAGA)	www.nasaga.org	Facilitate the use of simulations and games Principles and procedures of interactive, experiential approaches to education, training, management, problem solving and decision-making
Australian Simulation and Games Association (OzSAGA)	www.education.uts.edu.au/ozsaga	Promote the use of case materials and simulations in higher education and employment Design case materials to meet the needs of students for group working, decision making and experience of work
Swiss Austrian German Simulation and Gaming Association (SAGSAGA)	www.sagsaga.org	Promotion of experience-oriented learning Promotion of communication between professional users, developers and users of planning game methods in the private sector and in public Use and evaluation of planning game methods
Society for the Advancement of Simulation and Gaming in Education and Training (SAGSET)	www.simulations.co.uk/sagset/	Encourage and support the development of gaming, simulation and other forms of active learning in all aspects of education and training
Society of Simulation and Gaming of Singapore (SSAGSg)	www.ssagsg.org	Promote experiential activities in the public community
The Game Group	www.thegamegroup.com	Improving in-classroom training and learning Offer learning games as a training alternative
The Thiagi group	www.thiagi.com	Use games and activities that engage participants in learning and training Help people achieve more through performance-based training that is motivating and effective
Apply Serious Games	www.applyseriousgames.com	This is a yearly conference focusing on the applications of serious games
Simulation and advanced gaming environment for learning (Sage)	www.sageforlearning.ca	Apply technology based simulations and games for learning Integrate new technologies for effective use of simulation games in education
Game show presenter	www.almorale.com www.socialimpactgames.com	Offer a presentation software which can be customized according to the subject for effective use in learning and training
Social Impact Games		Offer various ready to use educational serious games in various subjects
Games2Train	www.games2train.com	Learning through game-based approach Provide a more effective solution to training and learning by using video and computer games to many learning processes and areas

(*Continued*)

Table 1 (*Continued*)

Organization	Website	Research activities
GamesParentsTeachers	www.games parentsteachers.com	Game resources for teachers, parents and gamers Contains game resources in English, social sciences, sciences, physics and mathematics
Department of Defense Game Developer Community	www.dodgame community.com	Research on the use of and development of games appropriate in the military applications
Mark Prensky	www.marcprensky.com	Provides custom designed learning games Consultation services on educational game design
The Education Arcade	www.educationarcade.org	Design and explore games which play an important role in learning
The Learning Federation	www.thelearnin gfederation.org	Creating improved learning and teaching by the use of information technology
The Masie Center	www.masieweb.com	Explores the use of cutting edge technology in the learning process
The LavaMind	www.lavamind.com/edu.html	Offers a number of educational learning tools for both teachers and students
Capstone management simulation	www.capsim.com	Develop business solution games which have been applied in various universities and schools

digital circuits using a simple spreadsheet program, which require very few resources.

Computer Security. Computer security learning is often an uninteresting activity and many times people find it difficult to understand the literature available. Irvine and Thompson [37] developed a computer simulation game to teach computer security principles. A virtual computer network was simulated wherein a player made choices to protect the network from both vandals and motivated professionals. The intent of the game is to tailor to a particular learning objective and present interfaces that can be used to add supplementary educational materials as well as student assessment tools.

Protocols. According to Shifroni and Ginat [38], teaching computer communication protocols in the traditional lecture based format resulted in a minority of students understanding the protocol. As an alternative way a simulation game was developed, in which the students themselves act as the protocols components. After playing the game, there was a discussion about the characteristics of the protocol learned. Groups of students are formed, one for each component of the protocol. Messages are sent between the groups according to the working principle of the protocol and other constraints. To teach the ''stop and wait protocol,'' five student groups are formed. The sending and receiving groups are located in separate rooms, and can com-

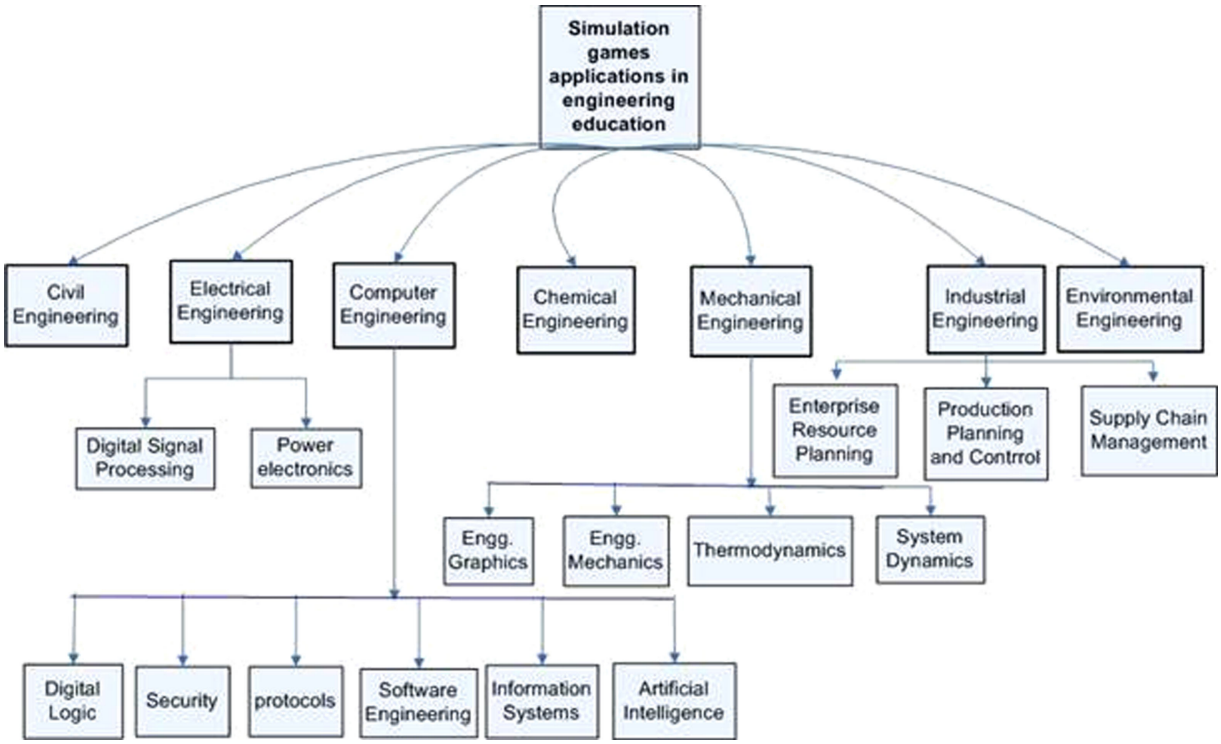

Figure 1 Application of simulation games in engineering education.

municate only through the services of the physical layer group. The teacher gives the network sender group a short message and then this group should use the services provided by the data-link sender group, in order to pass the message to the network receiver group. The aim is to have the message constructed by the network receiver group identical to the message originally given by the teacher. Shifroni and Ginat [38] stated that using this game in high school computer communication education fostered group co-operation and discovery learning, which improves self-learning and problem solving abilities.

Software Engineering. Generally, software engine-ering courses lack the practical experience of the process of a complete software development cycle. Students are taught theoretical process in lectures and have a limited opportunity to practice the skills in class assignments, case studies, and projects. Emily and André [39] developed an educational, interactive, and graphical *SimSE* simulation game that can be used to experience and solve real-world issues in software development. The game simulates an environment in which the player takes the role of the project manager and must manage employees to complete a particular task. Drappa and Ludewig [40] developed another simulation game SESAM in which the students manage a team of virtual employees to complete a software develop-ment project with given constraints. The major drawback with SESAM was that it did not have a graphical user interface. Claypool and Claypool [41] describe the implementation of a game-centric software engineering course. The game contains various modules, which deals with the software engineering process. The integration of the modules leads to a complete computer game. During the initial offering, class enrollment increased, dropouts reduced, and most importantly, the grades were improved.

Information Systems. Martin [42] developed the MIS game (non-computerized version) and the Information Systems Project Manager (computerized version), which offer innovative contributions to the teaching and learning of information systems. Players have a certain budget and are required to acquire and deploy resources to develop a portfolio of systems. They have the responsibility to identify a business requirement and acquire enough resources of cash and staff by moving their token around the perimeter track, representing resource management. Leemkuil et al. [43] describe the development of a collaborative Internet-based simulation game titled KM QUEST for learning to solve knowledge management problems. It is a three-player game, in which each player has the same role of knowledge manager who collaboratively have the task to improve the efficacy of the company's knowledge-based system. The goal of the simulation game is to optimize market share, profit, and the customer satisfaction index for the set conditions.

Artificial Intelligence. Gyllenskog [44] used the Konane game (also called as Hawaiian Checkers) to teach artificial intelligence. Later a computerized version of the game was also developed.

Chemical Engineering. The University of Michigan has developed *Vicher* (virtual chemical reaction module), a virtual reality application for under-graduate chemical reaction engineering education [45]. Vicher deals with the fundamental concepts in chemical engineering such as catalyst fouling, energy effects on reaction kinetics, reactor design, and effects of changing feed rates, inlet temperatures, etc., on reaction conditions. Rovner [46] explains the on going efforts for the development of the simulation game ''Virtual Lab'' at Purdue University. The game targets early-college students in chemistry that deals with chemical reaction of ammonia, which is needed to make fertilizer for plants.

Mechanical Engineering

Engineering Graphics. Crown [12,47] developed a number of web-based games using simple JavaScript code to enhance visualization skills essential in engineering graphics. Each game was developed as an individual HTML web page using simple JavaScript code (client-side processing) for the game logic. Various games in the field of multi-view drawings, auxiliary views construction, manipulation of parts, and a reference co-ordinate system in a three dimensional space are developed. Ireland's University of Limerick hosts the Spatial Intelligence website [48], which features 75 interactive exercises to help students develop their spatial abilities. Michigan Technological University offers interactive modules for learning the engineering graphics concepts [48]. The multimedia content website of Spanish Ministry of Education contains multimedia applications on technical drawing concepts for students.

Engineering Mechanics. Philpot et al. [4,49] developed several computer-based games, which are used in the statics and mechanics of material courses. These games are intended to help students grasp fundamental concepts and basic calculations in these courses.

Thermodynamics. Reed and Afjeh [50] developed an Internet based Java Gas Turbine Simulator, which allowed efficient construction and analysis of a gas turbine systems. The simulation consists of a graphical user interface and a gas turbine analysis method coded in JAVA, which can run on heterogeneous platforms. The package provides analytical, graphical, and data management tools that allow students to rapidly develop dynamic turbine gas simulations. Benson and Thomas [51] explain a workstation-based interactive educational tool, which is helpful to understand the turbojet engine design and analysis. The tool solves for flow conditions through the engine using classical one-dimensional thermodynamic analysis. The student can vary the design conditions through a graphical user interface (GUI) and the engine performance is calculated immediately for the changed conditions. The tool was further extended to model the performance of turbofans and afterburning turbojets [52]. There are also efforts to build aircraft design process using web-based modeling and simulation techniques [53].

System Dynamics. Mandal et al. [54] developed an internet-supported flexible learning environment for teaching system dynamics to engineers.

Industrial Engineering

Enterprise Resource Planning. Chwif and Barretto [5] developed a Didactic Operations Simulation Model (DOSM), which uses discrete event simulation as the main time advance mechanism. The first model ''central limit theorem explainer'' (CLT) aims to teach the concepts of central limit theorem. The second game called ''Mac Game'' show students how costs and revenues interact in a complex ERP system. SEQUEUM DOSM demonstrates the complexity of a scheduling problem having several scheduling rules. It has the functionality to observe the change in performance by varying the scheduling rules. Léger [8] described the application of a simulation game using various modules of SAP R/3 to teach ERP concepts to undergraduates and graduate students. The pedagogical objective of the game was to develop understanding of the concepts underlying enterprise systems, to experience the advantages of enterprise integration,

and to develop technical skill for using the ERP software. Adelsberger et al. [55] developed a simulation game ''MURSH-Bikes,'' whose processes and model is derived from a real bicycle manufacturing facility. The information processing of the game is modeled in the SAP R/3 system and the production processes are modeled with ARENA simulation system. The focus of the game is to help students understand the complete logistics chain and the business processes involved.

Production Planning and Control. Cox and Walker [56] stated that the production line balancing, planning, and control concepts are difficult to understand for students who do not have experience in a manufacturing firm. The non-computerized Socratic Dice & Penny game they developed help students understand the impact of constraints and non-constraints on output, quality, and line efficiency, and traditional, Kanban, and drum-buffer-rope scheduling. Bringelson et al. [57] developed the ''NCTB'' computer simulation game to help students make decisions in an interdisciplinary group. The focus was on teaching four functional areas; namely, purchasing, production planning and control, quality control, and marketing. The ''SimEnterprise'' simulation game mimics a micro world of business activities [58]. Students perform the role of trading firms where their task is to make optimum strategic, operational, and financial decisions. The objectives of the simulation game include understanding the interaction between purchasing, production, and sales marketing; gain experience in planning and control; and learn various business strategies. Hongyi [59] described a non-computerized game that simulates a car production process with manual paperwork and a set of poker cards. The main objective of the game is to understand the difference between material requirement planning and just-in-time production planning methods. Tommelein et al. [60] developed a parade game, which can be played either by hand using a dice or with the help of computer simulation. The game consists of a chain of trade processes where the resources produced by one trade are prerequisite to work performed by the next trade. The variability at each stage reduces the throughput, delays project completion, and increases waste. The objective of the game is to show that throughput can be increased by reducing the vari-ability of workflow at each stage in the system. Choo and Tommelein [61] further developed the ''Parade of Trade'' game, which simulates the dice game. They used Stroboscope [62] to simulate the Parade Game and collect statistics from the simulation. Alarcon and Ashley [63] used @Risk to simulate a slightly modified dice game to evaluate various production strategies. The INSIGHTS-PPC (production planning and control), INSIGHTS-POC (production operations controlling) and INSIGHTS-ORS (operations restruc-turing) games were developed under the CAESAR project which dealt with production planning and control, production planning evaluation, and re-engineering of distribution channels, respectively [64]. A number of simulation games in production management learning having varying pedagogical objectives were presented in [64]. They are summarized in Table 2.

Supply Chain Management. The Beer Distribution Game (Beer Game) was the first simulation game in the area of supply chain management created by a group of professors at MIT Sloan School of Management in the early 1960s. The aim was to meet customer demand for beer, through a multi-stage supply chain with minimal expenditure on back orders and inventory. The original beer game had many hindrances, lacked enough stages, and suffered from complexities like setup time to represent a realistic supply chain. Holweg and Bicheno [65] developed the ''Lean Leap Logistics Game'' in a steel manufacturing environment whose main objective was to create supply chain awareness and propose improvements. This game overcame the shortcomings of the beer game to model real world complexity of a supply chain. Sparling [66] further developed an advanced version of the beer game simulation using spreadsheets incorporating planning, forecasting, and inventory management activities. The Supply Chain Management Trading agent competition (TAC-SCM) is a web based multi-agent simulation platform developed at the Carnegie Mellon University [67]. This multi-player online simulation game deals with the bidding, sourcing, and procurement options in a typical supply chain under realistic conditions. Fawcett and McCarter [68] developed a non-computerized ''SC Puzzle Game'' to demonstrate the behavioral issues in supply chain coordination. The game highlighted that technology is not the panacea for supply chain transparency and coordi-nation but human behavioral issues play a vital role. Teaching such concepts is next to impossible in the traditional classroom setting. Aggarwal et al. [69] developed a supply chain simulation game in the area of post harvest produce sector, which serves as a tutorial for undergraduate course in food science. The game was developed under the Windows operating system environment using the Stella software to model the complex simulation equations.

Environmental Engineering. Hirose et al. [70] developed an industrial waste game for environ-mental education based on the garbage game [71]. The aim was to enable players to understand the social dilemma between individual interest of hazardous dumping and the social cost of purifying pollution, and to find a solution to the social dilemma by providing a monitoring and sanction system for illegal dumping. The authors stated that the debriefing sessions after the simulation game and the communication between students and the instructor is necessary for successful implementation of the simulation games in educational settings.

Jehng-Jung and Ying-Jie [6] developed a Windows based educational simulation game for water quality management. The aim was to assist novice engineers and students to learn water quality management by compromising among cost, water quality, and equity. The game structure is similar to the WQ game [72] developed at University of Illinois at Urbana-Champaign. The game exposed students to the conflicts and real world problems, which exists due to sparse resources, conflicts, and constraints in the area of water quality management. The other advantage of the game is that it was internet enabled and the user did not need to install it on his/her local machine; thus bypassing the need for administrative rights (which can be a problem in university/school computer laboratories).

Torres and Macedo [13] developed a card simulation game called Learning Sustainable Development (LSD) to create awareness and explore perceptions toward environmental conservation and urban development. The authors concluded that simulation games can be used effectively to create awareness of a novel concept in a particular field. LSD makes user think critically, ask question, and synthesize information by experiencing real-world problems.

Hansmann et al. [73] developed an online simulation game SIMULME to encourage positive environmental attitudes and to study effects of food consumption. COREBIFA, an interactive simulation game in the nutrition field, explains the hazards and creates awareness about daily nutrients consumption [74].

Table 2 Classification of Production Planning and Control Simulation Games

Name	Topic	Pedagogical objective	Description
Game with single decision maker			
TRAIN-F	Logistics processes	Know how	Study the effects of varying production planning parameters on logistics process via computer aided system
FMS design game	Flexible manufacturing system (FMS)	Understanding	Study the influence on loading and dispatching rule on the performance of FMS
OPT_SIM	Production planning	Understanding and know how	Simulates the various processes on a shop-floor
DIC_SIM	Supply chain management	Understanding and know how	Simulates a supply chain
Games with decision center			
Logtime	Production management	Awareness and understanding	Understand production management by performing activities like sales, assembly, quality control, etc.
The ruler game	Operations management	Awareness and understanding	Simulates a actual production facility of wooden rulers
Teamwork game	Team work principles	Understanding	Teams of three to eight members execute various assigned tasks and analyze group experiences
Planning of work structures	Production planning	Understanding	Understand issues in work structuring and validating the use of simulation techniques in production systems
NEW ORSIAM INT'L	Operations management	Know how	Understand and resolve issues by simulating the operation of a manufacturing firm
The shop floor scheduling game	Scheduling	Know how	Understand scheduling under uncertainty
Games with multifunctional interplay			
Lego truck	Production planning and control	Understanding and know how	Demonstrate planning and control of procurement, production, assembly and shipment in factory
CIM-Game	Production management	Understanding	Illustrate production management activities in an integrated manufacturing environment
Tailored order-to-delivery simulation game	Change management	Understanding	Demonstrate management of change towards lean manufacturing and order-to-delivery
The ADVANTIG	Implementing CAD/CAM/robots	Awareness	Demonstrate the issues of improving the production practices by implementing new technology
The GTI game at bang and olufsen	Improvement in an assembly section	Understanding	Simulated a assembly layout to understand the factors influencing through put
The logi game	Logistics	Understanding and know how	Management of logistics chain and material flow
Porte Alegre	Production management	Awareness	Uses war game concepts to learn manufacturing management via strategic and tactical plans

ANALYSIS

We summarize simulation games in Table 3 based on the following classifications:

- *Drill-based*: These are straightforward plug-and-crank games to observe a particular phenomenon or process. For example, study of change in economic order quantity with change in holding cost keeping all the other factors constant. The student can get valuable insights and determine the critical and non-critical factors affecting a particular quantity of interest.
- *Exercise-based*: These games require the student to choose the correct technique to solve a problem. The games assist students make decisions in a multidimensional environment,
- *Problem-based*: These games allow students to try several approaches depending on the assumptions made.

Table 3 Summary of Simulation Games

Game	Area	Computerized/ non-computerized	Type
[16]	Architecture	Computer based	Drill-based
[17]	Business ethics	Computer based	Problem -based
[18]	Child development	Non-computerized	Mini-case
[19]	Interviewing skills	Non-computerized	Exercise-based
[20]	Laboratory management	Computer based	Drill and exercise
[21]	Medical	Computer based	Problem-based
HEART-SENSE Game [22]	Medical	Computer based	Drill-based
Spectrum game [23]	Physics	Computer based	Drill-based
[25]	Physics	Computer based	Problem-based
Frantic Physics [24]	Physics and calculus	Computer based	Drill-type
Tic-Tac-Toe game [24]	Mathematics	Computer based	Exercise-based
[37]	Computer security	Computer based	Drill-based
SimSE [39]	Software engineering	Computer based	Mini-case based
SESAM [40]	Software engineering	Computer based	Mini-case based
[41]	Software engineering	Computer based	Mini-case based
Project Manager [42]	Information systems	Computer based	Mini-case based
KM QUEST [43]	Information systems	Computer based	Problem-based
[38]	Computer protocols	Non-computerized	Drill-based
MagicBlocks [11]	Digital logic	Computer based	Drill-based
Konane [44]	Artificial intelligence	Non-computerized	Drill-based
Industrial Waste game [70]	Environmental engineering	Non-computerized	Exercise-based
Educational water quality management game [6]	Environmental engineering	Computer based	Problem-based
Learning Sustainable Development [13]	Environmental engineering	Non-computerized	Exercise-based
Internet-based Interactive Construction Management Learning System [32]	Civil engineering	Computer based	Drill-based
[33]	Civil engineering	Computer based	Problem-based
[12]	Engineering graphics	Computer based	Drill-based
[4]	Engineering mechanics	Computer based	Drill-based
[54]	System dynamics	Computer based	Problem-based
[50]	Thermodynamics	Computer based	Drill-based
[51]	Thermodynamics	Computer based	Drill-based
[52]	Thermodynamics	Computer based	Drill-based
[5]	Enterprise resource planning	Computer based	Drill-based
[8]	Enterprise resource planning	Computer based	Mini-case based
MURSH-Bikes [55]	Enterprise resource planning	Computer based	Mini-case based
Socratic [56]	Production planning and control	Non-computerized	Drill-based
NCTB Game [57]	Production planning and control	Computer based	Mini-case based
SimEnterprise [58]	Production planning and control	Computer based	Mini-case based
[59]	Production planning and control	Non-computerized	Drill-based
[60]	Production planning and control	Non-computerized	Drill-based
Parade of trade [61]	Production planning and control	Computer based	Drill-based
[63]	Production planning and control	Computer based	Drill-based
Lean Leap Logistics Game [65]	Supply chain management	Non-computerized	Exercise based
[66]	Supply chain management	Non-computerized	Mini-case based
TAC-SCM [67]	Supply chain management	Computer based	Online multi player simulation competition
SC Puzzle Game[68]	Supply chain management	Non-computerized	Drill-based
[69]	Supply chain management	Computer based	Problem-based
Virtual Lab [46]	Chemical engineering	Computer based	Exercise based
Vicher [45]	Chemical engineering	Computer based	Drill-based
WinDSK [34]	Electrical engineering	Computer based	Drill-based
Interactive Power Electronics Seminar [35]	Electrical engineering	Computer based	Drill-based

- *Mini-case*: These games typically require students to recognize the appropriate need or opportunity. The students are given a scenario with suitable description and asked to come up with a solution satisfying the given constraints.

These simulation games mostly deal with a specific concept, phenomenon, or a process related to a subject. Future work must aim to develop applications having comprehensive functionality dealing with all the topics of the subject under consideration. This will give students a holistic understanding of the subject and the interrelation of various concepts with their application in the real world. Some initiatives like COSIGA (A concurrent engineering simulation game—using advanced multimedia and telecommunication for education of European Engineering Students) have been initiated. The focus of COSIGA is to use multimedia simulation games to train engineers in a multidimensional environment to enhance concurrent, co-operative and planned working principles. Globalization, technology advances, and increasing competition have changed the required qualification of engineering graduates. Future simulation games should allow individual and group gaming in multi-disciplinary, multi-national, multi-cultural, multi-language, and distributed environment [75].

Simulation games developed must constantly adjust themselves to the dynamic changes in the industry, myriad of new research avenues, and the latest technology platforms. Thus the object oriented principles of reuse and inheritance must be considered while designing and developing such applications. Further research is required for assessing the relationship between student learning and the use of computer-based games [4]. There is a need to develop new methods and procedures using computer medium for instruction to integrate these alternative and supplementary instructional tools into the overall teaching and learning effort. There is no formal method or standard procedure to evaluate efficacy of a simulation game technique against the traditional method. Future work must concentrate on developing such metric for evaluating the effectiveness of the simulation game under consideration.

CONCLUSION

Simulation games have promising applications in engineering education. However, the shift from traditional lecture-based education to simulation games-based education is gradual and still not widespread. Nonetheless, a large number of simulation games with various degrees of sophistication have been developed. It would be desirable for the game developers and textbook authors to work together to provide appropriate games as supplements to textbooks. On the other hand, existing simulation games deal with a particular concept, phenomenon, or process. There is a clear need for a virtually integrated and comprehensive simulation game applications that will enable holistic understanding of a subject where the students can interrelate various concepts, understand the tradeoff involved, resource constraints, and their practical significance. This will maximize the transferability of academic knowledge gained by students to practical tasks in the industry.

Implementation of simulation games in civil engineering education has shown encouraging results where the students learned various skills including management, engineering cost control, and teamwork [33]. Similar results have been reported in other fields of engineering like electrical engineering where the games led to a self-discovery process to better understand various communication protocols [38]. Better understanding of the enterprise level dynamics was among the reported benefits of simulation games in the industrial engineering education [8,56]. A number of studies confirmed that simulation games helped students increase their awareness of real world issues and comprehension of course subjects [12,49,70]. In another study, the use of simulations game encouraged students to spend more time on the analysis and alternatives than the minimum specified [5].

The new teaching methodology using simulation games will transform the instructor's role to a 'promoter' of knowledge as opposed to that of an 'agent' in the conventional environment. Similarly, students' role in this new environment is active rather than that of receptive in the traditional system. This strategy will encourage the instructor to explore ways where students can work effectively both individually and in groups. The game environment will attract more student attention and make tacit knowledge like perception, collective knowledge, conceptualization, analytical thinking, and experience more explicit. Thus, the use and further development of simulation games promises to uplift the engineering education and resolve the long-standing issues. It will also satisfy the industry demand for skilled workers having ability to work in competitive, inter-functional, individual and group environments.

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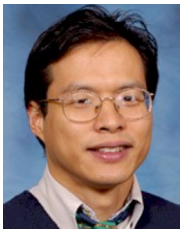

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