I, Shubham Sah, hereby submit this original work as part of the requirements for the degree of:
Master of Science
in Mechanical Engineering

It is entitled:
A Virtual Reality Based Progressive Learning Paradigm For Supply Chain Management Education

Student Signature: Shubham Sah

This work and its defense approved by:
Committee Chair: Hongdao Huang, PhD

_____________________________
A Virtual Reality Based Progressive Learning Paradigm For Supply Chain Management Education

A thesis submitted to the Graduate School of the University of Cincinnati in partial fulfillment of the requirements for the degree of

Master of Science

in the Department of Mechanical Engineering of the College of Engineering by

Shubham Sah

June 2010

Committee Chair: Dr. Samuel Huang
ABSTRACT

With dwindling enrollment and students’ attrition towards classrooms, it has now become necessary to find an innovative teaching methodology which inspires students and builds upon their interest in the subject matter. Educational games have often proved to be effective in offering students an alternative and a seemingly more interesting approach to learning. “Supply Chain, LIVE” is one such simulation based educational game for Supply Chain Management.

This tool is first of its kind in a sense that it primarily tries to simulate scenarios created out of course materials and tied to real-world problems. Behind the scenes is an entrepreneurial storyline which actually incorporates a number of engineering and mathematical concepts ranging from optimization to calculus to statistics. The tool is divided in three modules namely the Inventory Management Module, Forecasting Module and Aggregate Planning Module. Students having no prior knowledge can still ‘play’ this game and are exposed to these concepts in a seemingly simple way. Unlike the traditional classroom courses where students are overwhelmed with a wide range of concepts in a short span of time, the practical nature of this tool focuses on a few key concepts and ensures that students get ample time and practice before moving on to a newer concept or a higher difficulty level.

While these modules encourage active student participation in the course material, the Challenge Module, ensures that students truly understand the key concepts in supply chain management. This module adds a dynamic component to the traditionally static form of testing such as pop quizzes and written tests. It simulates a laptop supply chain in the form of a web-based team activity where students manage different companies within the supply chain, negotiate sales contracts, and plan company operations.
“Supply Chain, LIVE” is a concrete implementation of the problem-based learning pedagogy with additional features such as just-in-time tutoring, progressive learning, and collaborative problem solving. Compared to other supply chain simulation games, its uniqueness include (1) balancing engineering modeling and optimization with business strategy, (2) relating problem solving to career progression in a company to keep students motivated, (3) providing on-line help when needed to keep students engaged, and (4) supporting student interaction and collaborative problem solving to improve their communication and interpersonal skills.
ACKNOWLEDGEMENT

I am deeply indebted to Dr. Samuel Huang, my teacher and advisor for providing his valuable time and guidance throughout my graduate study. His constant encouragement and support towards experimenting new ideas really had me going. I am greatly honored to have worked under him.

Thank you, Saurabh for all your whacky ideas. Thank you for your help in setting up the database for this project.

Thank you to the fellow students from Intelligent Systems Labs for their constant support and encouragement.

Finally, thanks to my Mom and Dad for always supporting me. Everything good in my life is because of their blessings.
# Table of Contents

Abstract ............................................................................................................................ iii

Acknowledgements .......................................................................................................... v

Table of Contents .............................................................................................................. vi

List of Figures .................................................................................................................. viii

List of Tables .................................................................................................................... xi

1. **Introduction** .............................................................................................................. 2

   1.1 Problem Statement ................................................................................................. 2

   1.2 Background ............................................................................................................ 3

   1.3 Objectives and Tasks ............................................................................................. 5

   1.4 Layout .................................................................................................................... 6

2. **Literature Review** ..................................................................................................... 7

   2.1 Games in Education ............................................................................................... 7

   2.2 Simulation in Supply Chain Management .............................................................. 11

   2.3 Educational Games in Supply Chain Management ............................................... 15

   2.4 Engineering Pedagogy ........................................................................................... 18

      2.4.1 Problem based Learning .................................................................................. 21

      2.4.2 Use of Virtual Reality .................................................................................... 24

      2.4.3 Progressive Learning Methodology ............................................................... 26
2.5 Summary and Unique Features.................................................................29

3. Methodology ..............................................................................................32

3.1 Game Design and Philosophy .................................................................33

3.2 Inventory Management Module ..............................................................36

3.3 Forecasting Module .................................................................................40

3.4 Aggregate Planning Module ....................................................................44

3.5 Challenge Module ...................................................................................48

4. Implementation .........................................................................................50

4.1 Simulation Engine ..................................................................................51

4.2 Game Story .............................................................................................54

4.3 User Interaction and GUI Features .........................................................59

  4.3.1 Inventory Management Module .......................................................63

  4.3.2 Forecasting Module .........................................................................67

  4.3.3 Aggregate Planning Module .............................................................70

  4.3.3 The Supply Chain Challenge .............................................................72

5. Conclusion ..............................................................................................77

References .................................................................................................79

Appendix A – Technical Features................................................................88

Appendix B – The Supply Chain Challenge - Problem Statement ...............91
List of Figures

Figure 1.1: Global View of Dell’s Suppliers .................................................................................. 3

Figure 2.1: Applications of Serious Games .................................................................................. 8

Figure 2.2: Simulation process (Kelton et al 1991) .................................................................. 12

Figure 2.3: Modern day requirements of Engineering Pedagogy ............................................. 20

Figure 2.4: Pebble-in-the-Pond instructional strategy ............................................................... 22

Figure 2.5: ISMA’s PBL Mode ................................................................................................. 23

Figure 2.6: Michael Heim’s VR template .................................................................................. 25

Figure 2.7: Comparison of learning paradigms ....................................................................... 26

Figure 3.1: Modules and their respective scenarios ................................................................. 34

Figure 3.2: Supply Chain, LIVE Learning Methodology ......................................................... 35

Figure 3.3: Simulation Cycle for IMM ...................................................................................... 37

Figure 3.4: Applications of Forecasting .................................................................................. 40

Figure 3.5: Simulation Cycle for FM ...................................................................................... 43

Figure 3.6: Comparison in teaching styles for AP ................................................................. 45

Figure 3.7: Simulation Cycle for APM .................................................................................... 47

Figure 3.8: Activities of Challenge Module ............................................................................ 49

Figure 4.1: Schematic illustration of a laptop computer supply chain ...................................... 50

Figure 4.2: Box-Muller Transformation ................................................................................. 53
Figure 4.3: Arena’s Input Analyzer output .................................................................54
Figure 4.4: Main Menu of the Game ............................................................................55
Figure 4.5: Scenario Introduction Screen .................................................................56
Figure 4.6: Microsoft Genie Character .......................................................................58
Figure 4.7: Scrolling, Blinking Tips .............................................................................59
Figure 4.8: Genie reading out Introduction Screen ......................................................60
Figure 4.9: Results Screen .........................................................................................61
Figure 4.10: Genie Hint Window ................................................................................62
Figure 4.11: Inventory Management Module Scenario Menu ....................................63
Figure 4.12: GUI for Inventory Management Module ................................................64
Figure 4.13: Control Panel for IMM ..........................................................................65
Figure 4.14: Past Sales Record Screen .......................................................................66
Figure 4.15: Top Panel for IMM ................................................................................66
Figure 4.16: Forecasting Module Scenario Menu .......................................................67
Figure 4.17: GUI for Forecasting Module (FM) ..........................................................68
Figure 4.18: Control Panel for FM .............................................................................69
Figure 4.19: GUI for Aggregate Planning Module (APM) ...........................................70
Figure 4.20: Control Panel for APM ..........................................................................71
Figure 4.21: Dynamic Input User Alert box in APM ....................................................72
Figure 4.22: Contract Management Tool for Challenge Module ...............................73
Figure 4.23: Aggregate Plan Form for Challenge Module .................................................. 74

Figure 4.24: GUI for Challenge Module ........................................................................ 75

Figure 4.25: GUI for Challenge Module showing income statements ......................... 76

Figure A.2.1: Class Diagram .......................................................................................... 90
List of Tables

Table 3.1: Skills and knowledge to be acquired in IMM .................................................37
Table 3.2: Skills and knowledge to be acquired in FM .................................................41
Table 3.3: Skills and knowledge to be acquired in APM .................................................44
"If we can integrate games within learning across the curriculum we can make education the proper competition for our children's minds."

-Nolan Bushnell, Founder of Atari, father of the video game industry
1. INTRODUCTION

1.1 Problem Statement

Higher education in general is going through a transformation phase with engineering education in particular facing significant challenges like falling students’ enrollment and student attrition [1]. Thus it has become necessary to develop an innovative teaching strategy which attracts students and accommodates their different learning styles and preferences. Research has shown that experiential learning can be a useful pedagogy to meet these needs [2]. The overall objective of this thesis is to develop and implement a problem based progressive learning methodology within an integrated virtual enterprise framework. The proposed methodology should be able to motivate students to effectively acquire theoretical knowledge as well as practical decision-making skills.

Educational games fair much better in attracting the attention of students when compared to teaching in the traditional classrooms or reading books. These games achieve higher levels of student concentrations and are helpful in developing critical thinking and decision making skills [3]. Supply Chain Management has gained tremendous amount of importance in the business world in recent times. This increased popularity has reflected upon the academia where SCM is now taught as a separate course. The challenge is to create one such educational tool for Supply Chain Management which complements the concepts taught in the classroom. Once proved effective the methodology can then be extended to other courses across the engineering academia. Acting as the missing dimension, the game should be capable of presenting the theoretical concepts in a way which is more interesting to students. This educational tool should be able to present the serious concepts of the course in a playful environment and should be able to address any doubts or questions arising in the students’ minds. The game should promote
independent thinking amongst the students and provide students ample time and practice for better understanding and application.

1.2 Background

The world has seen a rapid amount of globalization in recent times. Trade barriers are being cut down, profit margins are shrinking and as a result firms are always on the lookout for new and innovative costs cutting solutions. This has led to long and complex trading networks spread across the globe. The figure 1.1 below shows the global stretch of Dell’s supply chain. The process of making a raw material available as a finished product to a consumer is no longer a simple one. Today when you walk into an electronics retail store to buy a laptop, you begin what is a called a supply chain.

![Figure 1.1: Global View of Dell’s Suppliers](image)

*Figure 1.1: Global View of Dell’s Suppliers [4]*
The consumer’s demand begins the supply chain and it stretches across national and international borders to include each and every party involved in making a product available to a consumer. It includes the raw material suppliers, the distributors the retailers, the manufactures and the logistics service providers (hereby referred to as the different entities of a supply chain).

As individuals each entity has a different functional focus within the supply chain. A retailer tries to balance his inventory with the consumer demand. A manufacturer is always on the lookout for a perfect production plan. Similarly, a logistics service provider has to deal with route scheduling and network optimization problems. However, the underlying objective for all entities is to minimize the costs associated with their respective functions. Supply Chain Management combines a set of scientific principles which aims at minimizing these costs and at the same time increasing the efficiency of the supply chain as a whole.

Traditionally, Supply Chain Management principles have been an integral part of the business curricula. However with their ever increasing significance and use, they have now invaded the engineering curriculum as well. Several universities have begun specialized courses which address various supply chain related topics inside the classroom. Concepts such as inventory management, forecasting, and aggregate planning and network optimization are covered in a classroom environment. These courses generally include a class project where students are they simulate a virtual laptop supply chain physically inside the classroom. Students act as various supply chain entities and interact with each other in a virtual corporate supply chain environment. Apart from the topics mentioned earlier a project may also involve students in additional tasks like contract negotiating and supplier selection. The simulation game, Supply Chain, LIVE, developed as a part of this thesis is an attempt to create a virtual reality based progressive teaching model for supply chain management education.
1.3 Objectives and Tasks

The purpose of this thesis is to address the above mentioned shortcomings of the current engineering pedagogy. The primary objectives and tasks of this thesis are as follows.

- To update the traditional engineering methodology in a way that is more suited to the new generation of students.

- This methodology should provide students with a step by step approach in which they start with simple fundamentals and gradually move towards more complex concepts. It should also provide ample time and practice for better understanding.

- Integrating problem based learning into the methodology which changes the focus to “Learn by doing” rather than “Doing by learning”.

- Implement the methodology into a simulation based application, for Supply Chain Management, that covers the entire course structure and acts as a learning aid. It should give the students an opportunity to indulge themselves into the educational concepts for more active learning.

- Use of simulation based scenarios so that students can review the effects of their decisions and strategies without any fear of failure or penalty. Compared to the real world experience, this would ensure that an accelerated learning takes place.

- The tool should have a user friendly interface which is simple and easy to comprehend for the students. Graphical aids should be used as much as possible to attract their attention and get them interested in playing the game.
1.4 Layout of the Thesis

The thesis is divided in five chapters. The first chapter consists of the Introduction, which covers the background and problem statement. This is followed by the second chapter, the Literature Review, featuring a review of the research that has been done previously in the areas of simulation games and supply chain management simulation.

The third chapter covers the teaching methodology along with a description of the concepts covered in Supply Chain, LIVE. The fourth chapter discusses the user interaction features of Supply Chain, LIVE in detail. Finally, the fifth chapter has the conclusion and scope for future work. The chapters are followed by a list of references and appendices.
2. LITERATURE REVIEW

Business schools have been traditionally known to employ educational games as teaching aids. Areas such as finance, organizational behavior, human resources and general management have good support available in the form of such learning tools [5]. These tools are considered to be as innovative learning methods and have been around since late 1950’s [6]. These games originated from the work on war games in militaries in which theories of combat were tested in simulated scenarios. Since then several noted researchers have devoted their time in evaluating the efficacy of such simulation based tools as compared to the traditional teaching methods. This chapter presents a summary of the various developments that have taken place in this field.

2.1 Games in Education

Anthropology tells us that simulation games have been around since prehistoric times when children used to mimic adults’ activities such as hunting and nursing. Imitating these activities was done primarily as games and served as training and learning exercises. We as kids have been through a myriad of educational games taking form of some of the popular board and card games. It has been suggested before that games, as part of leaning environment, fit perfectly into the philosophy of active learning and constructivism [7]. Several other noted researchers have corroborated this theory from time to time.

In 2003, Klassen and Willoughby wrote a paper in which they developed an inventory simulation game and methods to evaluate its efficacy [11]. The results proved that students gained a better understanding of inventory management after they had played the game. As mentioned earlier educational games have been part of the business curricula for a long time. It has been reported by Fario that approximately 97.5% of accredited business schools use simulation games as
pedagogical aids [12]. Their popularity with the business community can be attributed to the fact that in 1995, Heineke and Meile, came out with a book completely devoted to games and exercises for teaching operations management [13]. Figure 2.1 below lists some of the many applications of Serious Games.

Abt coined an interesting term to differentiate these leaning tools from the regular games. He called them “Serious Games”, the adjective serious being added to represent the use of such games for something other than pure entertainment [14]. These could be anything ranging from defense, education, scientific exploration, health care, emergency management, city planning, engineering, religion or politics. Zyda, in his article in IEEE in 2005, updated the definition for Serious Games with a more logical approach [15]. His definitions were:

Game: “a physical or mental contest, played according to specific rules, with the goal of amusing or rewarding the participant.”

Video Game: “a mental contest, played with a computer according to certain rules for amusement, recreation, or winning a stake.”
Serious Game: “a mental contest, played with a computer in accordance with specific rules that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives.”

In 2002, Professor Angela Macfarlane of University of Bristol reported the findings of a study conducted by BBC where she advocated the use of some hardcore commercial games (such as SimCity 3000, The Sims series and Age of Empires) as part of actual school curriculum [16]. It was found that these games had significant educational value and developed children’s strategic thinking and planning skills. Recently, Dostal has termed these educational games as “tools of modern education” in the Journal of Technology and Information Education Information [3].

Computer aided instructions methodologies were not popular until the personal computers became popular in the late 1980s [17]. Kehagias and Vlachos studied the efficiency of computer aided teaching for Business Calculus to college freshmen through a control experiment [18]. They found that the computer aided course was a useful improvement over the traditional one with a more apparent student involvement. A similar study was conducted by Mills in 2001, who studies the effectiveness of such computer aided methods in an industrial setting. Mills was able to identify advantages with these methods such as ability for the learner to self pace his learning and the recovery of the high development cost with repeated use [19].

Recently, the Woodrow Wilson International Center for Scholars in Washington D.C. launched a "Serious Games Initiative" to encourage the development of games having high pedagogical effectiveness [20] [21]. This combined with the massive popularity of computer based games and the emergence of online multiplayer games has drawn some serious attention from all over the
world. Consequently, more focused groups began to appear in this emerging field. These include organizations such as ‘Games for Change’ which focuses on social issues and social change, conferences like ‘Games for Health’ which addresses health care applications and the ‘Game based Learning’ conference in 2009 [22] [23].

The ever growing popularity and practicality of such tools has been examined by a number of researchers [24-31]. Virvou, Katsionis and Manos evaluated the educational efficacy of combing software games with education [32]. Basing their analysis on the premise that computer games are popular among adolescents, they proposed that educational software could be exploited to make learning more attracting and motivating. The results of their evaluation showed that virtual reality games were indeed more effective with students and more importantly, with students having poor performance in areas taught prior to their learning experiences with the games.

Serious games focusing on teaching management and business principles are classified as business simulation games or economic simulation games. Chan’s highly popular Capitalism (Trevor Chan’s Capitalism, 1995 and Capitalism II, 2001) was called the best business simulation game ever by the review website IGN Entertainment [33]. The game has players building and controlling a business empire and covers various aspects of business like marketing, manufacturing, purchasing, importing, and retailing. Capitalism was designed to run on a Windows based PC and had very well defined help tutorials.

**2.2 Simulation in Supply Chain Management**

Simulation is defined as the imitation of any real world system by creating a mathematical model to study its characteristics. It is a very powerful tool which allows us to evaluate the performance
of a system before actually implementing it in real world situations. It enabled us to perform what-if analyses in a simulated environment leading to better decision making and permits comparison of various alternatives without disturbing the actual system. Hollocks for instance, labeled simulation an operations research technique that involves the creation of a computer program representing a portion of the real world [34]. He further stated that the benefit of simulation lies in the fact that experiments done in a simulation model can predict what will happen in reality. Before Hollocks and Pedgen had called simulation a process of designing a computer model for a real system and conducting experiments with this model to understand its behavior and devise strategies for its operations [35].

Among the many advantages of simulation is the ability to make better and more informed decisions and improved risk management. This has led to a widespread use of simulation as part of daily activities of engineering and business analysts as a tool to check and propose solutions to problems commonly found in different industry sectors. Banks & Carsen, Pedgen, Law & Kelton have all summarized a typical simulation process or project into nine essential steps as shown in Figure 2.2 [35-37].

Simulation uses powerful mathematical tools like probability and statistics for modeling of the events in a real world system and thus is very efficient in capturing its dynamics. Besides, its inherent nature eliminates the large amount of risk involved in something like a supply chain and allows test of several scenarios before making critical changes in planning process.
With computers becoming more powerful than ever, creation and analysis of complex mathematical models has simplified considerably. This has been like a boon to the relatively newer simulation softwares, adding to their popularity as tremendous modeling and analysis tools. Consequently, the term ‘simulation’ is now synonymous to computer controlled
simulation. Computer based simulation tools are now extensively used to gain insights into the working of many physical and abstract systems like healthcare delivery, supermarkets, city planning, airports, banking systems, flight and marine simulators, robotics and computer networks, satellite navigation systems.

Although a lot of comprehensive research material is available with regard to supply chains, the literature is limited when it comes to simulation in supply chains. Several scholars including have published material on simulation of rather simple supply chain models [38-48].

Simulation is particularly useful in studying the working of supply chains due to their inherent complexity. Besides, the graphical and animation aids that accompany today’s simulation tools make the study of supply chains even more exciting. As a result, many people have devoted their time and study to this upcoming field. Chang and Makatsoris addressed some issues regarding basic requirements for supply chain simulation [44]. They identified the importance of coordination between the various entities in a supply chain and stressed upon the use of discrete event simulation for evaluating supply chain performance. They further stressed upon the importance of simplifying the various levels of supply chain for better understanding. Special mention was made for proper and extensive data collection for proper modeling.

Kleijnen and Smits identified four main types of simulation possible in supply chain management [49]. These were spreadsheet simulation, system dynamics (SD), discreet event dynamic systems (DEDS) simulations and business games. They stated that each of these had a special functional focus like spreadsheets being part of production control software and SD simulation may be helpful in explaining the bullwhip effect. Similarly, DEDS simulation was found useful in predicting fill rate values and business games were effective in educating and
training users. Kleijnen went on to publish a supply chain simulation survey in the International Journal of Simulation and Process Modeling. Importance of sensitivity and robustness analyses of a supply chain simulation model was highlighted and a new methodology for the same was proposed [50].

Lee, McLean and Umeda examined a preliminary model for a manufacturing supply chain based on a power-tools manufacturing company. This was done as part of the MISSION project (Intelligent Manufacturing Systems (IMS) Modeling and Simulation Environments for Design, Planning and Operation of Globally Distributed Enterprises). Their objective was to develop a prototype information model which could be further used to integrate the various distributed models developed by individual entities of the supply chain [51].

Rockwell Arena is a very popular simulation and automation software used for modeling and simulation purposes. Vieira used Arena to develop a simulation model to aid professionals from management to evaluate the performance of supply chains. He developed what he called a basic supply chain model in Arena and focused on two performance measures namely inventory level and customer service level [52]. Wu et al. developed a model for supply chain in the manufacturing industry at University of Cambridge [53]. They collected information from potential customers and reproduced the production planning and scheduling of suppliers in Arena. They recommended that information sharing between the customer and suppliers betters the performance of supply chain. They also established the fact that simulation tools are capable of simulating information sharing successfully.
2.3 Educational Games in Supply Chain Management

As mentioned earlier, a common pedagogical technique followed in business curricula is make students participate in a “business game”. Students divided into small teams imitate a business setting, for instance competing as different business firms in a virtual market. Marketing experts say that the best way to get people to do what you want is to make them want to do it and we have already established that humans are wired for play as games are a powerful and primal method of motivation.

Who hasn’t played the classic Beer Game (Systems Dynamic Group, MIT) in a basic supply chain management class? Ever since it was developed, this highly effective game has been used extensively for explaining the bull whip effect and the importance of forecasting in a supply chain. Originally played inside the classroom as a physical simulation, the game is now available online and has inspired many version and variations. One such variation is the Near Beer Game, developed by Forio Business Solutions and available online for free. This game has a slightly different objective and focuses more on achieving demand equilibrium in a supply chain.

Dr. Sunil Chopra, a noted author in the field of supply chains, and his colleague Philipp Afeche developed an online simulation game focusing on inventory management, network optimization and facility location models. Houten (Delft University of Technology, Faculty of Technology, Policy and Management, Systems Engineering Section) started the Global Supply Chain Games (GSCG) project in collaboration with University of Maryland R.H. Smith School of Business Supply Chain Management Center. A series of Distributor Games were developed under this project, again as online simulations. The objective was to manage the complexities of global sourcing in a complex virtual market with products that quickly lose their value [54].
The Virtual Factory research group at Georgia Tech, headed by Dr. McGinnis, designed a similar game centered on the automotive industry. Students playing as manufacturers, transport companies, first-tier suppliers, second-tier suppliers etc… are made to see the impact of their decisions, for better or worse, and learn about supply chain dynamics. The University of Greenwich, Business School hosted a Supply Chain Business Game where players are made to take over an already established production facility having a couple of distribution centers. Focus was on problems which are generally faced by real executives with lesser initial knowledge about an established business.

Finch and McGraw-Hill came out with a book titled “Interactive Models for Operations and Supply Chain Management” [55]. The book is accompanied by a CDROM having various mathematical models used in supply chain management designed as small Java Applets. These were designed to run in any java supported browser giving the students to change various parameters within a model to observe its effects. However, ironically the applets were hardly interactive and just seem like dumb computer programs for the models already mentioned in hundreds of other book.

In 2007 Siddiqui, Khan and Akhtar developed a scenario based supply chain simulation game called SBELP [56]. Their game, designed in Macromedia Flash MX, simulated a simple supply chain addressed topics such as the value of information flow in a supply chain and observing the bull whip effect. The tool was put to test at KFUPM, Saudi Arabia for an introductory supply chain course for a period of four semesters. Positive feedback from the course instructors and students indicated the enormous amount of potential such products have as possible leaning aids. Anderson and Morris published a paper on their educational game called the Mortgage Service Game. This was another online simulation game for supply chains having multiple, potentially
autonomous players performing a sequence of operations in make-to-order setting with the focal points being contract negotiation and capacity management [57].

It’s not only the research institutions and people from academia that have shown interest in the development of business games. Management Utilities, an Italian based company known for endorsing modern training and learning methodologies, has developed a hoard of simulation games targeted specifically for educational purposes in areas like general management, retail, sales, marketing and networking. Their supply chain game has players operate a sanitary devices company and supply its products to final customers who buy in retail shops, to wholesalers and exporters (following the make-to-buy approach) and to public administration and bidders (following make-to-order approach).

In 2003, TAC, an international forum designed to promote and encourage high quality research into the trading agent problem, came out with a simulation game focusing on supply chain management [58]. This game, abbreviated as TAC SCM, depicts the scenario of a personal computer assembly supply chain, consisting of a PC assembler, suppliers who supply components for the PC assembly. During the course of the game the players are required to place bids for their respective components and negotiate contracts for successful bids. The game also focuses on the information sharing aspect of supply chain management. Similarly, MTA International’s Woodhead and Thompson developed ‘KanDo Lean’, an activity based fun game where players have to set up a production facility and produce a variety of products to their customer’s specifications. Focus is on Kanban concept of just-in-time production and lean manufacturing [59].
The idea of simulation games for education has also attracted some of the giant business firms such as DPWN and L’Oreal. In 2008, Deustche Post World Net, world leader in logistics services, sponsored and hosted an internet based simulation game, Discover Logistics, focusing on logistical aspects of supply chain management [60]. This game attracted participation from all over the world and was unique in the sense that players competed with each other instead of a computer. Information was first collected from all player teams and then simulation was used to generate the affects of the decisions made by the respective teams. Cosmetics giant L’Oreal has been hoisting a similar online business simulation game called EStrat for almost a decade now. EStrat has players managing a virtual cosmetics firm and deal with decisions involving pricing, production, research and development, marketing, advertising and brand value [61].

2.4 Engineering Pedagogy

Any country’s strength is directly related to the strength of its economy. In the early months of 2008 United States entered into a period of financial crisis. Experts such as Alan Greenspan, ex-Chairman of the Federal Reserve, dubbed this period as the “harshest since the end of World War II” [62]. The recession brought along a cycle of bankruptcies, credit crunches, deflation, foreclosures and unemployment. United States is also facing lot of challenges from the developing economies of the BRIC (Brazil, Russia, India and China) countries. In 2001, Goldman Sachs predicted that the combined economies of the BRICs are likely to overtake the combined economies of the current richest countries of the world by 2050 [63].

Rapid technological advances, on the other hand, have made us increasingly dependent on information technology services. This combined with the threat from increasing global
competition calls for the need of a highly skilled workforce. The Economic strength of any nation heavily relies on a workforce with expertise in the STEM (Science, Technology, Engineering, and Mathematics) courses. However, reduced interest in these fields has led to a dipping enrollment which has created a workforce void. Realization of taking necessary steps to fill this void and be better prepared for these impending challenges is very important, although, deciding on the best possible strategy to tackle this issue remains a matter of debate [1].

What could be reason behind this alarming issue of ever declining students’ interest in STEM courses? This problem seems to have originated from the traditional and long-established pedagogical techniques. From ages we have followed the same class room lecture style teaching paradigm where the students act as mere receptors of education. Being a tried and tested method for so long, it may seem unlikely that this highly successful technique is the culprit here. However, times have changed and the world now moves at a frantic pace. How can we expect one particular teaching methodology to be equally effective with all kinds of modern day students? This is not a new observation but has already been echoed throughout the academia quite often (NRC 2000) [64]. For instance, Prayaga et al at the University of West Florida proposed some innovative methods to motivate students to pursue STEM related courses [65]. Strategies such curriculum redesign, novel University/Industry partnerships, K-12 outreach activities, and building awareness for STEM within the community were successfully implemented. Figure 2.3 below summarizes the modern needs of engineering pedagogy.
Another example is MIT which hosts a website, “MIT OpenCourseWare”, allowing free public access to virtually all of its course content. The website has a comprehensive collection of lecture notes and presentations. Similarly, Stanford University has put more than 600 lecture videos for a variety of courses on YouTube. These innovative methods do allow one to study and learn at one’s own pace and style. However, barring the change in the education delivering medium, they still rely on the traditional classroom style of teaching.

The pedagogical techniques concerning engineering education, in particular, have always been infamous amongst undergraduate students for being *not engaging enough* or sometimes even considered as *irrelevant*. As a result most students gradually lose interest in the educational concepts and either give up or stick around only to receive bad grades. This further dents their confidence in engineering education. Up till now it was argued that these students are not simply...
suited for engineering education. Simultaneously, though it was also believed by several people that the fault may be in the traditional educational paradigm itself which has failed a number of students [66-67]. Unlike other areas, engineering education is dynamic and ever evolving. It requires a more active approach, one which depends more on visual and tactile form of learning. This brings to the primary objective of this thesis which is to identify the requirements of modern day engineering education.

2.4.1 Problem based Learning

Problem-based learning is a student centric learning methodology where students are gradually given more and more responsibility of their education. The idea is to reduce their dependence on the instructor in order to promote independent thinking and application. The instructors on the other hand act just as facilitators of education. One of the first instances where PBL was followed practically was at McMaster University Medical School over 25 years ago. Since then several undergraduate and graduate programs around the world have applied PBL to their curriculum. Barrows et al. (Southern Illinois University School of Medicine) defined PBL as a mixture of both a curriculum and a process [68]. A curriculum consisting of carefully selected and designed problems that promote self learning. Along with theoretical concepts, the students learn team participation skills and develop their critical thinking. As a process PBL replicates real life scenarios where students learn systemic problem solving techniques.

The innovative feature of PBL is the drastic role change for students and instructors. Increased responsibility for students means better self motivation and more feelings of accomplishment. Students’ confidence soars with good quality learning and knowledge thus gained is retained for
a longer period of time. On the other hand the instructors become resources of education with their main job being that of guidance and evaluation. Several researchers and have already corroborated this theory before. [1]

![Diagram of Merrill’s Pebble-in-the-Pond instructional strategy](image)

*Figure 2.4: Merill’s Pebble-in-the-Pond instructional strategy [70]*

In 2002, David Merrill came up with a new teaching model which he called as *Pebble-in-the-Pond* [69]. Fig. 2.4 summarizes this methodology, essentially a PBL based technique, where circles depict the progression of problems, the triangle in the background depicts the gradually decreasing role of the instructor and the components are the knowledge acquired with each of the problems. The Illinois Mathematics and Science Academy started their PBL Network way back in 1992 and ever since have successfully provided teachers and students, throughout Illinois, opportunities to excel in STEM courses. Figure 2.5 below shows the PBL model devised by IMSA.
Singapore’s Republic Polytechnic is the first professional institution which follows PBL pedagogy for all its courses. RP follows a *One-Day-One-Problem* learning approach where students are required to concentrate on a single subject each day. Similarly, Mastrich University in Netherlands has also embraced PBL since its inception. Some other examples of PBL initiatives include ones by Penn State University, West Virginia School of Osteopathic Medicine and Illinois Math and Science Academy.

Although PBL has gained much popularity amongst academia ever since it was introduced, some researchers think otherwise. Sweller *et al.*, in 2006, conducted a study with an algebra course and concluded that the most effective strategy was to use working examples in the early stages complemented with PBL introduced in the advanced stages of the learning process [71]. Newman *et al.* put forward similar observations on PBL effectiveness [72].
2.4.2 Use of Virtual Reality

Virtual Reality is a generic term used to describe a technology which allows interaction between a human and a computer simulated environment. When we think of VR, we think of futuristic science fiction based 3D environments but behind the scenes are complex computational models designed specifically for visual perception. Given the fact that basic computer technology has established itself as an essential part of educational curriculum all over the world, VR which is still in its nascent form, holds a lot of potential in learning environments. Heim, a respected author in this filed and popularly known the philosopher of cyberspace, created a template for VR [73]. He defined VR using seven distinct concepts shown below in figure 2.6.

Perception is nothing but how a human brain processes any incoming information. Approximately 80% of incoming information is visual in nature [74]. Past studies suggest that engineers like to visualize things and thus for an engineer, visual perception is very important for proper understanding of the subject matter. The traditional teaching styles have generally ignored this fact. Demetry and Groccia pointed out that exclusive use of lectures creates a passive learning environment for students where they tend to be just spectators [75]. This approach results in a “teach me” attitude rather than promoting interest, curiosity and self learning. John
Shaffer, a seventh grade science teacher at the Academy School District Twenty in Colorado, wrote a paper discussing the potential effect VR has on the visual and auditory cortex growth [76]. He advocated the use of VR to enhance a person’s physiological or psychological response towards education.

In a time of our ever growing dependence on computers, technology based learning environments are more suited for today’s generation of students. Along with the regular clerical work, computers are extensively used nowadays for lab experiments and research work. So in a way computer facilitated education already exists at some level, however, the idea here is to take it to the next level. Extensive use of VR promises to refine the existing engineering pedagogy to
develop a completely new and positive way of experiencing education. It has the ability to transform engineering education into an exciting learning experience.

2.4.3 Progressive Learning Methodology

In the words of the great Greek philosopher Aristotle, "For the things we have to learn before we can do them, we learn by doing them. Progressive Learning, the third pillar of this novel educational methodology, is where students learn from their own mistakes and successes to move up the education ladder. PL ensures that complete and in-depth learning takes place through an interactive learning experience. Peer discussion provides motivation and promotes active learning with students getting more time for trying innovative ideas.

**Fig 2.7: Comparison of the learning paradigms**
The figure 2.7 above summarizes the essential steps of a Progressive Learning model as compared with the traditional style learning model. Consider an example where a student has to be taught a simple concept such as Economic Order Quantity (EOQ). In the traditional style of learning, the student will directly learn the formula for calculating EOQ either from a text book or from an instructor. Next comes the application session where the formula is applied to problems directly. Finally the instructor returns into the picture for evaluation of the application. If the student gets it right, he moves on without actually understanding the concept. To make matters worse, if he gets it wrong then the correct answer is spoon-fed to him. Did the student really learn anything apart from a mathematical equation?

On the contrary, a progressive learning environment works differently. Consider a scenario where the student directly encounters the problem of finding the optimal order quantity without any prior knowledge of the EOQ concept. Using simulation, real time demand can be generated which provides a dynamic learning environment. This allows the student to get a feel of how things actually work in real life. Starting with a simple strategy, the student may try to order a certain amount (say equal to the opening inventory) of the product whenever it is out of stock. After doing so for a while the student would realize that the ordering cost is too high if the opening inventory is low (because of high ordering frequency). On the other hand, if the opening inventory is high then the inventory cost (capital cost + storage cost) would be too high because of the large cycle inventory. This situation would lead the student to search for an appropriate ordering quantity/frequency and gradually he reaches a point where the concept of EOQ automatically starts to make sense. This whole process ensures gradual learning which further lays the foundation for better understanding of the subject matter.
Progressive from of learning and education was popularized by John Dewey, a leading practitioner of the progressive movement in U.S. schooling. [77]. Dewey’s thoughts were based on the principle that humans are social animals who learn best when engaged in real-life activities with other people. Therefore learning takes place primarily by self reflection, a concept essentially lost in traditional style didactic pedagogy.

Being primarily student centric, this methodology calls for greater responsibility on the part of the students. *With power comes responsibility!* Kolb, an American educational theorist, came up with a theory saying that acquiring knowledge through personal and environmental experiences is a perpetual process [78]. However, according to him certain requirements must be fulfilled for experiential learning.

*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.*

Why is progressive learning effective? Is it because PL connects with the learner at a more personal level and promotes innovative thinking? Or is it because it provides an independent leaning milieu encouraging deeper and purer involvement? Confucius, an ancient Chinese philosopher once said, "Tell me and I will forget, show me and I may remember, involve me and I will understand.”
2.5 Unique Features

In this chapter a number of simulation-based educational products were reviewed. This list could on forever as we saw that several people, both from the business and academic fields, have devoted their time and effort to this area. The products mentioned above form a very meager percentage of similar educational products. There is no denying the fact that these products can be used as effective tools for education. Coming back to the focal area, Supply Chain management, some simulations and educational games mentioned above focused entirely on SCM while related to it. All games do form what can be called an innovative learning methodology and are gaining popularity as effective teaching tools. However, do these tools successfully address the challenges faced by engineering education in US?

*Is the status quo of educational games good enough for teaching purposes or there is scope for improvement? Is there a need and is it really possible to make the present model more comprehensive and efficient?*

This brings us to the premise of this thesis which addresses these issues. This thesis proposes a new teaching and learning methodology which aims at bridging the gap between modern day education and students. It combines innovative features of a problem based progressive learning methodology in a virtual reality based environment. Following are the unique features of this new methodology.

**Forming a well defined teaching methodology, one which inspires students and builds upon their interest in the subject matter.** Self inspired learning is the best form of acquiring education because of the real interest that a student has in the subject matter. All students have their so called “favorites” when it comes to education. The added interest in the subject allows a
student to excel and achieve better grades. A good learning methodology should be modeled on this fact. Rather than being rigid and forcing the student to come to it, it should be flexible and attract the student towards itself. This actually builds the student interest into the subject matter and thus better quality learning and understanding can be achieved.

The proposed methodology should be problem based and progressive, it should allow a student to make a decision and observe its affects. This will ensure that students learn from their mistakes. The second unique feature of this learning methodology is allowing a student to make mistakes. In a normal pedagogical setting, the basic idea is to prevent mistakes. Students learn several theories and concepts during a course of period and then are tested on their retention. There is very little room for making mistakes and without making mistakes the student is left devoid of exploring other avenues of education. Only surface learning takes place and the student’s focus is just to get a good grade to pass the course, rather than actually learn something. By allowing a student to make mistakes, this new learning methodology, promotes a much deeper learning.

Introduce fun elements into education for enriching the whole learning process. A Game based learning approach is much better suited for the younger generation. Young students are generally hooked on to games in various forms. The idea of learning in a gaming based fun environment rather than the regular classroom approach is bound to generate more interest among students. Of course, books may be required as supplements for such educational games as well.

The implementation of the proposed methodology in a virtual reality based environment considering the fact that such environments would bond quickly with today’s “digital
student”. Apart from integration of games, the new learning methodology should take advantage of the digital world as much as possible. Students today are more comfortable in such environments and integrating the use of computers into this new methodology only adds to the effectiveness. A bigger percentage of students can be attracted to the coursework if education is provided in the form of computers based games.

The methodology should allow the students to learn at their own convenient time and pace. One of the biggest challenges that educators face today is keep a student interested in the subject matter for a longer period of time. Young students inherently tend to lose interest in courses which require more time to master. A more student centric method would ensure that the student remains engaged in the subject matter rather than giving up easily.

Real theoretical concepts should be integrated into the learning methodology for proper education. Having all the above listed unique features does not mean that we can compromise on the theories and concepts involved in the subject matter. We just want a new approach to the teaching methodology with all the course content remaining pure and intact. Therefore, it is very critical that the learning methodology follows a strict course structure.

Now that we have identified the modern requirements of engineering education, the next step is to implement these features. In the coming chapter we take a look at Supply Chain, LIVE, a simulation game based on the proposed methodology.
3. METHODOLOGY

In this chapter we will cover the proposed learning methodology in detail. We have already defined the features that make Supply Chain, LIVE unique. It offers a teaching style which is significantly different from the traditional style of engineering education. Besides, it is much more effective than the so called existing educational games in the field of supply chain management. We will also take a look at the learning objectives of the game, the practical skills involved within each module and the theoretical knowledge that a student will acquire while playing the respective modules.

The specific objective of *Supply Chain, LIVE* is to present a multi-source active learning environment for students to undergo a motivation-based learning experience. This is the implementation of the newly proposed learning methodology. So, this game should be considered as an educational tool, which can be used by students to learn and practice the core concepts involved in the field of Supply Chain Management. Instructors can also think of it as a pedagogical aid to accelerate the learning process.

Supply Chain Management is a science in itself which has evolved from the traditional Operations Research concepts. It is a more comprehensive form of quantitative management and is more relevant in today’s “demand dictates supply” kind of markets. Covering all the activities of Supply Chain Management in this simulation game was neither practical nor possible. However, this game should be considered as the first step towards implementation of the proposed learning model and therefore it game provides an integrated environment covering three basic and essential components of SCM. These are inventory management, demand forecasting and aggregate planning. Apart from these, the game also encompasses a number of
supporting theoretical concepts like integer programming, material requirement planning, supplier selection, optimization using Excel Solver etc... This game is more like an introductory course rather than an advanced level course as the level of detail is not high and a lot of assumptions are into place.

3.1 Game Design and Philosophy

SCM is cross functional and inter organizational in nature with all involved the involved parties striving to facilitate the movement of finished goods out to the end consumer. To increase their flexibility in operations, the organizations strive to reduce their costs, such as raw material ownership or distribution costs, through outsourcing these functions to other smaller entities. This increases the number of supply chain partners and a need arises to devise concepts and principles which aim to improve trust and collaboration among them.

These principles, collectively called supply chain management, govern the various activities associated with SCM. The activities can be broadly classified as strategic, tactical or operational in nature and three of these activities were identified to form the core part of this game. Inventory Management, Demand Forecasting and Aggregate Planning thus became the three core modules for this game. Each of these represents an important functional area of SCM. To further simplify and facilitate the learning process, each of the modules are further broken down into several scenarios or in actual gaming terms "levels." In a normal game the levels serve as different checkpoints within the game separated by the difficulty of skill involved. The figure 3.1 below lists all the modules and their respective scenarios that are a part of Supply Chain, LIVE.
Similarly, in an educational game such as ours, the scenarios take the game forward either by changing the existing simulation parameters or by introducing new constraints into the game. The scenarios make sure that the students are introduced to the concepts in a proper way, which in turn ensures better understanding. After successful completion of all the scenarios, a student is well aware of the basic functionality of supply chain management. Whatever a student learns through the modules is through individual channels as individual functions. However, a real world supply chain is a complex integration of all these functions. This need is fulfilled by the game’s final module, the “Supply Chain Challenge.”
Student selects a module.

Gets a briefing for the scenario (problem statement)

Makes decisions and enters values

Runs (first trial) / Re-runs the simulation

Simulation results are displayed

Results are optimum?

Yes

Student Proceeds to the next scenario…

No

Restarts the scenario and prepares for simulation

Uses the inbuilt ‘hints’ for better understanding of the underlying concept

Student Proceeds to the next module…

Once finished with all modules individually, the students play the “Supply Chain Challenge” as a group activity and observe the integration of all the concepts at a single place.

Use of modules and scenarios ensure a problem based approach.

Simulation allows the student to quickly see the effect of their decisions and promotes progressive learning.

Students experiences how a supply chain works in real life. Peer discussion further promotes progressive learning.

Figure 3.2: Supply Chain, LIVE’s learning methodology
The “Supply Chain Challenge” brings all the functions onto a single stage and provides students with a chance to practice their supply chain skills in a competitive setting. This group activity serves as the perfect culmination for this educational game. The figure 3.2 above describes the complete learning methodology of Supply Chain, LIVE.

3.2 Inventory Management Module

Inventory Management has always played a very important role in improving supply chain performance. Inventory management is an integral part of SCM and unlike some other functions is usually associated with all the entities in a supply chain. Popular modern day terms, such as Lean, Kanban and JIT, all have their roots in basic inventory management. Success of retail giants like Walmart and Dell can be largely attributed to their good inventory management practices. Their success has inspired a whole new functional area popularly known as 3PL, which is the integration of the transportation and warehousing functions of a supply chain. Wikipedia defines a third-party logistics provider (abbreviated 3PL, or sometimes TPL) as “a firm that provides outsourced or third party logistics services to companies for part, or sometimes all of their supply chain management function”.

Supply Chain Management is more or less concerned with increasing the inventory visibility and velocity along the supply chain. A good understanding of inventory management principles usually translates itself onto an improved supply chain performance. Basic concepts such as order quantity, replenishment policies and costs associated with holding and ordering play a very critical role in reducing the overall operating costs. This module aims at giving the student an introductory but an in depth understanding of the various inventory management principles.
<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>Practical Skills</th>
<th>Theoretical Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>A new beginning</em>...</td>
<td>Constant demand scenario with no inventory restrictions. Determining the right order quantity and replenishment policy.</td>
<td>Simple EOQ (Economic Order Quantity) Model</td>
</tr>
<tr>
<td><em>Inventory troubles</em>...</td>
<td>Determining the right order quantity and replenishment policy with limited inventory space.</td>
<td>Modified EOQ with storage cost</td>
</tr>
<tr>
<td><em>Logistics simplified</em>...</td>
<td>Determining the right order quantity and replenishment policy and selecting a shipping option which minimizes costs.</td>
<td>Effect of shipping cost on the EOQ.</td>
</tr>
<tr>
<td><em>Life in Metropolis</em>...</td>
<td>Determining the right order quantity and replenishment policy in a realistic demand scenario.</td>
<td>Stochastic demand, Lead Time, Costs associated with under stocking and overstocking, Cycle Service Level, Re-order point and Safety Inventory.</td>
</tr>
<tr>
<td><em>Expanding the arsenal</em>...</td>
<td>Determining the right order quantity and replenishment policy with multiple products having varying demands.</td>
<td>Tailored Aggregation for multiple products.</td>
</tr>
</tbody>
</table>

*Table 3.1: Skills and knowledge to be acquired in IMM*
Table 3.1 above provides a summary of the various scenarios in the inventory management module. Along with the scenario names, it lists the practical and theoretical skills involved in the respective scenarios. The module starts with a basic constant demand model along with unlimited storage space and the only cost associated with inventory being the interest cost. The student here is expected to figure out the right order quantity using the basic Economic Order Quantity (EOQ) equation. In the second scenario warehouse restrictions come into the picture and the student has to figure out how will they affect the EOQ and the store’s replenishment policy from the first scenario. Similarly, in third scenario the student has to deal with new shipping options and figure out the one that minimizes the ordering cost. The fourth scenario introduces stochastic demand along with the concepts such as delivery lead time, safety inventory, customer service level and inventory re-order point. Finally the fifth scenario brings along inventory management principles concerning multiple products. Decisions such as placing individual orders or grouping the products together by using tailored aggregation come into the picture. The figure 3.3 below shows a typical simulation cycle for this module.
Figure 3.3: Simulation cycle for Inventory Management Module
3.3 Forecasting Module

Forecasting is the prediction of a future variable using statistical techniques on historical data. Basic statistical forecasting has been used extensively in a number of different applications. Figure 3.4 below lists some of the areas known for extensive use of forecasting techniques. In a business setting forecasting refers to the estimation of demand so that one can be better prepared for the future. With the climbing rate of globalization, competition amongst businesses has multiplied. Consumers are now more informed than ever and have more choices and hence the demand is becoming even more uncertain and volatile. Combine this with technological advances and the situation worsens.

Figure 3.4: Some applications of Forecasting
With the advent of JIT, Lean and Continuous Improvement eliminating waste has become the new success mantra for all businesses. Forecasting therefore is useful as it helps in decision making for future and take better control of inventory and production. Obviously, every business faces a time when sales do not go according to the plan. Accuracy in forecasting is something that one can just hope for because demand forecast are always wrong! Nevertheless forecasting remains an essential part of SCM and is the focus for this module.

Forecasting methods can be both qualitative and quantitative. Qualitative forecasting is when educated guesses are made based on judgment and experience. Quantitative methods generally use statistics, time series or regression, for making estimation. Whatever be the method, past sales data always plays a crucial role in forecasting. Supply Chain, LIVE covers three demand scenarios as shown in Table 3.2 below. Although a player is free to make judgment based forecasts, the module focuses on some of the quantitative forecasting models, suitable for their respective demand scenarios.

<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>Practical Skills</th>
<th>Theoretical Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Hit or miss...</em></td>
<td>Forecasting stochastic demand having no trend or seasonality.</td>
<td>Constant Model, Moving Average Model and Simple Exponential Smoothing Model</td>
</tr>
<tr>
<td><em>Burgeoning demand</em></td>
<td>Forecasting demand having a growth trend.</td>
<td>Static Linear Model, Linear Exponential Smoothing Model</td>
</tr>
<tr>
<td><em>Seasonal traits</em></td>
<td>Forecasting demand having trend and seasonality.</td>
<td>Deseasonalizing sales data and Simple Linear Regression. Use of Microsoft Excel.</td>
</tr>
</tbody>
</table>

*Table 3.2: Skills and knowledge to be acquired in FM*
The game requires a player to submit an annual demand forecast at the start of each simulation year. Actual demand is then simulated and the player’s performance is judged based on the resulting forecast error. If the forecasted quantity is too high for the actual demand, inventory is build up and holding costs increase. If the forecasted quantity is not sufficient to meet demand, the player has to place additional orders and bear high ordering costs. The player is discouraged to place additional orders because of high cost associated with them.

The first scenario kicks off with normally distributed stochastic demand without any trends or seasonality. This scenario covers some basic forecasting models such as Constant Model, Moving Average Model and Simple Exponential Smoothing Model. In the second scenario the player learn to tackle a linearly growing demand pattern with Static Linear and Linear Exponential Smoothing Models. Finally in the third scenario the player gets to experience seasonal demand. Concepts of seasonality, seasonal indices and deseasonalizing demand for forecasting come into picture. A player learns to do forecasting using the simple linear regression model.

Use of Microsoft Excel is encouraged for calculation of forecasts. Videos showing the whole forecasting techniques such as Linear Regression Model and De-seasonalizing the demand are integrated into the Genie Consultations. The videos combined with a dynamic game setting ensures that a player can learn at his own pace and convenience. The simulation cycle for the forecasting module is shown below in figure 3.5.
Player checks past sales record and submits forecast for the upcoming year

Read fixed variables (cost price, sell price etc…) and player’s decisions from the console

Read simulation variables (current inventory and backorders if any) from the console

Is the bank balance positive?

End of simulation?

Yes

Reset all variables, display results and exit simulation

No

Shipments arrive from the OEM, update store’s inventory

Simulate demand for current month

Yes

Update Inventories, add sales and sales revenue

No

Store’s inventory is able to satisfy demand?

Yes

Calculate backorders

Place additional orders

Calculate holding costs, record bank balance and kill backorders

Update console and increase month counter

Figure 3.5: Simulation cycle for Forecasting Module
3.4 Aggregate Planning Module

Aggregate planning is an important supply chain activity which allows the management to be better prepared for future demand fluctuations. An aggregate plan for the upcoming period, usually 2 to 12 months, is made for all the production activities of the plant. Using various inputs such as demand forecast, quantity of outsourcing, subcontracting of items, overtime of labor, numbers to be hired and fired in each period and the amount of inventory to be held in stock and to be backlogged for each period, the total cost and expected profit is calculated [79].

<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>Practical Skills</th>
<th>Theoretical Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level...</td>
<td>Using Microsoft Excel Solver for creating an optimum aggregate plan</td>
<td>Level Strategy of Aggregate Planning</td>
</tr>
<tr>
<td>Capacity...</td>
<td></td>
<td>Capacity Strategy of Aggregate Planning, Concept of overtime</td>
</tr>
<tr>
<td>Chase...</td>
<td></td>
<td>Chase Strategy of Aggregate Planning, Concept of hiring and layoffs</td>
</tr>
</tbody>
</table>

*Table 3.3: Aggregate Planning Module Scenarios*

The table 4.3 above lists all the scenarios in this module. The main idea behind this module is to teach students how to match supply with demand. Demand, due to its inherent nature and dependence on a host other external factors, is extremely volatile. Three common aggregate planning methods are employed in common practice based on the situation at hand. The scenarios in this module are designed around these three strategies.
Figure 3.6: Comparison of teaching style for Aggregate Planning

<table>
<thead>
<tr>
<th>Traditional Lecture Style Teaching</th>
<th>Supply Chain, LIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student learns theoretical concept from a textbook or from an instructor</td>
<td>Student, having no prior knowledge of aggregate planning, encounters a virtual environment allowing him to experience production planning</td>
</tr>
<tr>
<td>Gets a problem statement listing all variables and constraints</td>
<td>Studies forecasted demand to estimate monthly production and enters an aggregate plan for production</td>
</tr>
<tr>
<td>Studies forecasted demand to estimate monthly production</td>
<td>Simulation allows generation of real time demand</td>
</tr>
<tr>
<td>Selects a production strategy (Level, Capacity or Chase)</td>
<td>Simulation results are displayed immediately</td>
</tr>
<tr>
<td>Prepares an integer programming model and replicates it on to a spreadsheet</td>
<td>The student is motivated to improve profit and in the process learns about the various aggregate planning strategies.</td>
</tr>
<tr>
<td>Optimizes the model and calculates expected profit</td>
<td>Re-runs the simulation searching for a better solution and in the process better quality learning takes place</td>
</tr>
<tr>
<td>Finally gets an actual demand scenario to calculate actual profit</td>
<td></td>
</tr>
<tr>
<td>Repeats all the steps above for different production strategies to find one which gives maximum profit.</td>
<td></td>
</tr>
</tbody>
</table>
Instead of real time simulation, this module applies a more direct approach where the student is allowed to proceed only if his input values are capable of producing a feasible solution to the problem. In the first scenario, the student deals with a simple stochastic demand. Production quantities and required workforce decisions are entered into the game. It is checked immediately whether the quantities entered produce a feasible solution. If not then the player is asked to change his input values until a valid solution is possible. If yes, then the results are displayed which allows the player to check the accuracy of his aggregate plan.

The second scenario introduces the concept of overtime hours into the same environment. Finally, the third and final scenario introduces the concepts of seasonal demand and variable workforce. This brings in an additional responsibility of managing workforce on the production floor. Players deal with concepts of hiring and laying-off workers and their respective advantages and tradeoffs.

The dynamic nature of learning is what makes this learning most effective. Instead of learning all the concepts beforehand, the student is directly exposed to production planning decisions. Simulation allows real time demand generation and the student learns by making mistakes and correcting them. The aggregate plan is modified on the by making on the spot decisions. This promotes a healthy “learn by doing” environment and student ends up being actively involved in the education process. Learning in such virtually simulated environments prepares the student for application in the real world. The flowchart in figure 3.7 below summarizes the simulation cycle for this module.
Player studies retailer’s forecast and estimates an initial aggregate plan for laptop production and order quantities for the batteries and DVD. Student selects inventory alert levels in case the aggregate plan needs to be changed.

Figure 3.7: Simulation cycle for Aggregate Planning Module

47
3.5 Challenge Module

Let us move away from learning methodologies and focus on the testing methodologies. In a traditional classroom style of teaching instructors generally use pop quizzes and written tests to test the students’ knowledge. These allow the instructors to judge and grade students in a competitive setting. Students get a chance to apply their knowledge to problems similar to what they have learned in the course. This testing approach is very static and monotonous. In most of the cases the problems that students get in the quizzes and tests are very similar to the ones in the text books. There is always a possibility that a student can pass in these exams by just memorizing the concepts instead of actually understanding them. Therefore the idea here is to move away from this static approach and make the testing process dynamic. The various objectives of this module are as follows

1. To make the testing process more dynamic by giving students a chance to apply their knowledge in real world problems using a simulated environment.

2. To ensure that students have actually understood the educational concepts behind supply chain management and not just memorized them to get a good grade.

3. If possible, to make the testing process stress free and enjoyable so that students can be an active part of it.

The complete problem statement for the Challenge Module can be found in Appendix C. For “Supply Chain, LIVE”, the challenge module introduces a number of new concepts. This is a web based multiplayer activity where students play as teams. As expected, this module
encompasses all the three modules and their respective activities. The figure 3.8 below lists the various activities of Challenge Module.

![Figure 3.8: Activities of Challenge Module](image)

Teams of students act as the different players in a virtual laptop supply chain. A total of eight teams comprising of two retailers, two OEMs and four suppliers complete the supply chain. Apart from the three modules, this group activity brings in contract negotiation, another important aspect of supply chain. Teams negotiate sales contract amongst them and upload their finalized contracts and respective aggregate plans to an online central database. Finally, using all this information the challenge module simulates a supply chain based on a pre-selected demand scenario. The performance is measured on the basis of the “Profit Margin” registered by the teams.
4. IMPLEMENTATION

In this chapter we take a look at “Supply Chain, LIVE”, a simulation game designed for supply chain management education. The game is an implementation of the proposed methodology and encompasses its three core ideas. It offers a virtual reality based environment that supports progressive learning through an integrated problem solving approach. The objective of this simulation game is to provide students with an opportunity to experience as well as to study the operations of supply chain management.

‘Supply Chain, LIVE’ is designed to allow students to operate in virtual environments like a retail store or a manufacturing unit. Figure 4.1 below shows a schematic illustration of a typical laptop supply chain. The computer generates random demands and keeps track of the inventory during the simulation with the student making various ordering and production decisions. Once the simulation is complete the computer displays results including costs incurred, sales made, sales revenue collected, profits made etc.…

![Figure 4.1: Schematic illustration of a laptop computer supply chain (Huang) [1]](image-url)
Simulation allows the student feedback and results of their decisions in no time and students gain an intuitive feeling for the concepts and their respective solution techniques. The student thus experiences an interactive learning session which serves as a bridge between the course contents and their application in real world scenarios. This chapter will present a brief overview of the educational game ‘Supply Chain, LIVE’. We begin with discussing the story behind the game, followed by a description of the game’s GUI and user interaction features.

4.1 Simulation Engine

Unpredictability is an inherent property of all games; it is what that makes the game interesting. Without any randomness a player would easily beat the game every time following a fixed set of instructions. Will that be any fun? Most simulation games rely on random numbers to provide this unpredictability; even boards games use dice or number spinners or cards to introduce randomness. A perfect application of random numbers is something like consumer demand at an electronics retail store. No one can predict the exact number of customers who will visit a store (if one could then SCM would not have existed!) on a particular day.

Getting a computer to generate random numbers is a little complex, definitely not as easy as rolling a dice or picking a card. The fact is that computers are unable to generate true random numbers and use an algorithm to generate numbers which appear random. However, a short sequence of these pseudorandom numbers works perfectly in almost all. Most Random Number Generators (RNG) use a starting value called the “seed”. The number generated with the seed is then used as a seed for the next random number [80].
Peter Hellekalek et al (University of Salzburg, Austria) maintain a website containing comprehensive information about various RNGs. Visual Basic has a built-in RNG in the form of a statement called `Randomize` and a function called `Rnd`. The algorithm used for number generation is called Linear Congruential Generator, defined as follows [81].

\[
X_{n+1} = (ax_n + c) \ Mod \ m
\]

Where \(X_n\) is the sequence of pseudorandom numbers,

\[
0 < m, the \ modulus \ (m = 2^{24}),
\]
\[
0 < a < m, the \ multiplier \ (a = 1140671485),
\]
\[
0 \leq c < m, the \ increment \ (c = 12820163),
\]
\[
0 \leq X_0 < m, is \ the \ seed \ value.
\]

The numbers produced by LCG is very sensitive to the choice of coefficients \(c\), \(m\) and \(a\) and critical for good implementation of the algorithm. The values in brackets indicate the constants used by most Microsoft compilers including VB.

The uncertainty in demand is usually estimated (Chopra et al, Supply Chain Management, 2007) using the average demand and the standard deviation of the demand in a given period [82]. For this game, it was assumed that the demand is normally distributed. The random numbers generated by VB always lie between 0 and 1 with equal probability for each of the values generated. In other words, it could be called a continuous uniform distribution. George Edward Pelham Box and Mervin Edgar Muller developed the Box-Muller transformation (Figure 4.2) for
generating a two-dimensional bivariate normal distribution from a source of uniformly distributed random numbers [83].

![Diagram of Box-Muller Transformation]

*Figure 4.2: Box-Muller Transformation by Derrick Coetze [84]*

The transformation takes the form of the following two equations.

\[
\begin{align*}
    z_1 &= \sqrt{-2 \ln x_1} \cos (2\pi x_2) \\
    z_2 &= \sqrt{-2 \ln x_1} \sin (2\pi x_2)
\end{align*}
\]

If \(x_1\) and \(x_2\) are uniformly and independently distributed between 0 and 1, then \(z_1\) and \(z_2\) follow a standard normal distribution. The following figure shows how the uniformly distributed values (the initial circles uniformly spaced about the origin) transform into normally distributed values (circles more close near the origin and quickly spreading out).
Figure 4.3: Arena’s Input Analyzer’s best fit output for a sample of 1000 past demand values generated by “Supply Chain, LIVE” having a mean of 1000 and standard deviation of 250

The code used in this program generates two normally distributed random numbers which are then scaled using the desired mean and sigma values. Using Arena’s Input Analyzer, a set of 1000 random numbers generated by the game was plotted for best fit. The results in figure 4.3 confirm the accuracy of the simulation engine.

4.2 Game Story

The Oxford English Dictionary describes role-playing games (commonly abbreviated as RPGs) as “games in which players take on the roles of imaginary characters, usually in a setting created by a referee, and thereby vicariously experience the imagined adventures of these characters.” A good storyline is essential for such games because it establishes a connection with the user and makes the game playing experience more enjoyable. However, in a pedagogical setting such as ours, the primary purpose of the story deviates from making the game “enjoyable” to making the
game more effective. Calling “Supply Chain, LIVE” as the first ever real educational RPG for Supply Chain Management is not an overstatement.

Figure 4.4: Main Menu of the game

The game may look very basic without any high-end graphics, however, it teaches some of the core concepts of SCM good enough for an introductory level course. Supply Chain, LIVE, is the story of a young entrepreneur who starts of as a retail store manager and progresses to being a Supply Manager at a Laptop OEM. Figure 4.4 shows the Main Menu of the game showing options such as “Entrepreneurial Mode”, “Challenge Mode” and “Exit”. The Entrepreneurial
Mode is further divided into three main modules which take the story forward. The story begins with the inventory management module where the player starts off his career as the manager of an electronics retail store, Best Value Electronics. BVE is a reputed electronics retail store giant and the player is in charge of BVE’s store located in a small fictional town aptly called Staidville. The figure 4.5 below shows a typical scenario introduction screen where the player is made aware of the current situation and upcoming tasks.

Figure 4.5: Scenario introduction screen
The first scenario has the player manage fixed demand, make decisions on order quantity and replenishment policy for the store. The inventory management module has five scenarios with each running for a period of 52 simulation weeks. The main scoring point during the game is the store’s bank account. The bank account has to be maintained positive at all times and if it falls below zero, the player has to restart the scenario. Each scenario starts with a bank loan carrying an interest which the player has to take into account while making inventory decisions. Besides, the account also earns interest for maintaining positive balance.

The second scenario has the city mayor put up “some limitations on the warehouse space” and so the player has to operate with a limited inventory space. The third scenario sees the arrival of a new logistics service provider (LSP) in the city offering an alternative solution for shipping the laptops. After completing the third scenario the player moves to a bigger city, Metropolis”, and takes charge of a bigger store with stochastic demand for laptops. Finally the fifth scenario has BVE expanding the store to include desktops and HDTVs along with laptops.

With the forecasting module, the primary task of the player shifts from managing store’s inventory to forecasting demand. The forecasting duty is part of a new deal between BVE and Interstate, the LSP, where the retail stores are required to submit their annual demand forecasts to Interstate beforehand. This module operates on a monthly basis with each simulation year running for a period of twelve months. The player has access to past two year’s demand and is exposed to concepts of demand trends and seasonality.

The events in the third module take place after a period of five years where the player has left BVE and joined the Bell Inc, the laptop OEM as their Supply Manager. The player has to now head the production planning and control department of Bell’s plant located in the outskirts of
Metropolis. Annual demand forecast from the retailers is made available to the player and the focus now shifts towards aggregate planning.

The term *Game Master (or Game Manager)* is commonly associated with all role playing games. The main job of a Game Master is to introduce the story, the characters and other objects of the game and set up the game’s environment for the player. In this game along with storytelling, the Game Master also provides general help and hints throughout the game. Microsoft Agent Control 2.0 (Figure 4.6 below) is embedded in *Supply Chain, LIVE* as the Game Master and takes charge as the teaching component of this educational game.

![Figure 4.6: The Game Master - A Microsoft Agent 2.0 “Genie”](image)

Introducing playful elements into actual course material and creating the game like environment for education requires a lot of creativity, planning and designing skills. The story sets the stage for the game’s modules and scenarios and forms a valuable communication link between the
player and the game. A good story keeps the player interested into the game, a function critical in making an educational game even more effective.

4.3 User Interaction and GUI Features

Supply Chain, LIVE is based on a student centric learning methodology and thus good user interaction features are critical in making the game effective. The importance of visual learning for an engineer has already been discussed before. With the visual appearance and user interaction features being the direct points of communication, it is important that they are designed in a way that appeals to the student and holds their interest into the subject matter. Figure 4.7 below shows one such communication aid of this game.

Fig 4.7: Scrolling hints, blinking texts appear during the game play to assist the player

One good example is the growing popularity of Linden Lab’s Second Life as a virtual learning environment. It is now being used by over 300 universities from around the globe for teaching courses and conducting research [85]. Supply Chain, LIVE incorporates several visual aids such as scrolling tips, blinking dialog boxes and an animated genie to interact with the player. Along with a solid dose of theoretical concepts such visual aids act as refreshing agents and keep the student interested. Figure 4.8 below shows the Genie giving the player an introduction of the scenario.
In a pedagogical setting, good visual aids gain even more importance as they become a necessary component of the game. They should be able to properly guide a first time player, one who may not have any prior knowledge of the theoretical concepts involved in the modules. For instance, each scenario in the inventory management module has a “correct” order quantity and replenishment policy which yields the maximum possible profit. If the player is able to identify it correctly, he or she is free to play the next scenario in the game. However, if not (figure 4.9) then the player has to play the same scenario again. The Genie appears (looking disappointed of course!) and communicates to the player what needs to be done to get things right.

Figure 4.8: Genie reading out the introduction screen
Since the game is built on actual course material, the theoretical concepts are embedded into the modules and are available in the form of *Genie Consultations*. Figure 4.10 below shows the Genie providing one such hint to the player playing the first scenario of the inventory management module. To make things even more interesting, the hints always appear in a way that keeps the player guessing. The correct answer is not communicated directly to the player but through a series of hints which first explain the underlying theory. Hints dent the store’s bank balance by $10,000 as a onetime “Consultation Fee”. This promotes independent thinking from the player as he tries to save money by avoiding using hints.

---

**Figure 4.9: Results screen**

Since the game is built on actual course material, the theoretical concepts are embedded into the modules and are available in the form of *Genie Consultations*. Figure 4.10 below shows the Genie providing one such hint to the player playing the first scenario of the inventory management module. To make things even more interesting, the hints always appear in a way that keeps the player guessing. The correct answer is not communicated directly to the player but through a series of hints which first explain the underlying theory. Hints dent the store’s bank balance by $10,000 as a onetime “Consultation Fee”. This promotes independent thinking from the player as he tries to save money by avoiding using hints.
Figure 4.10: Genie providing a hint (consultation) to the game
4.3.1 Inventory Management Module

The inventory management module is all about handling the retail store’s warehouse. It involves identifying the right order quantity and replenishment policy for the store and decisions such as selecting a shipping method which minimizes the ordering costs. The store’s past two year’s sales records are made available. The player is encouraged to use it for predicting the demand for the upcoming year. Figure 4.11 below shows the menu screen for the Inventory Management Module with all the five scenarios in the module. The player can either begin a new game by starting with level 1 or by directly jumping to a higher level of difficulty.

Figure 4.11: Inventory Management Module Scenario Menu
Figure 4.12: GUI for Inventory Management Module

Figure 4.12 above shows a typical game play screen during simulation. The GUI is divided into several distinct panels for increasing clarity and usability. The Control Panel acts as the interface between the player and the game. It serves two important functions. Firstly, it allows the player to control the simulation. The Start button allows the player to begin the simulation, the speed control mechanism located right next to the Start button allows the player to control the speed of the simulation. Figure 4.13 below shows an enlarged view of the Control Panel. All the inventory control decisions are entered into the control panel at the start of the simulation.
The “Past Sales record” button displays the sales record window (Figure 4.14) and “Consultation” button activates Genie, the game master. The top panel (Figure 4.15) displays the simulation data including the current week, corresponding actual demand and the bank balance. The supply chain view panel and warehouse panel work as the visual aids and display the current inventory in numerical and graphical forms respectively.
Figure 4.14: Past sales record screen showing data (fixed demand) and chart

Figure 4.15: Top Panel for the Inventory Management Module
4.3.2 Forecasting Module

The Forecasting Module shifts the focus towards demand forecasting for the store’s future demand one product at a time. It involves identifying the correct trend or seasonality in past demand and applying an appropriate forecasting technique for the upcoming demand. The store’s past three year’s monthly sales records are made available to the player for analysis. The player is encouraged to use Microsoft Excel as the analysis tool for predicting the demand. Figure 4.16 below shows the menu screen for this module with all the three scenarios. Each scenario has the player dealing with a different product having a different demand pattern.

Figure 4.16: Forecasting Module Scenario Menu
The GUI for this module is shown above in figure 4.17. The Control Panel, again acting as the interface between the player and the game, allows the player to control the simulation. Besides the usual, the “Past Sales record” button displays the sales record window where the player has access to sales data for past three years. The “Consultation” button invokes the game master. The player has an option of reviewing the demand forecast each month based on actual demand enabling a more dynamic adaptive forecasting method.

![Forecasting module GUI](image)

**Figure 4.17:** Forecasting module GUI
The lower portion of the GUI has two charts, both working in real time. The first chart plots the demand forecast, the actual demand and sales made each month. The second chart plots the Tracking Signal, which allows the player to keep track of the forecasting performance. The Figure 4.18 below shows the control panel of this module.

![Control Panel for the Forecasting Module](image)

**Figure 4.18: Control Panel for the Forecasting Module**
4.3.3 Aggregate Planning Module

The third and final module is the Aggregate Planning Module which shifts the focus towards creating an optimum aggregate plan and estimating profit using the Microsoft Excel Solver. The player’s role shifts to being in charge of production planning decisions at the fictional Bell Inc. This involves identifying the appropriate production quantities and required workforce to meet the upcoming demand. The demand forecast is made available to the player as a starting point. Figure 4.19 below shows the GUI for the Aggregate Planning module. Instead of the usual Start button, we have a Submit button as no demand is simulated here.

![Figure 4.19: GUI for Aggregate Planning Module](image-url)
An enlarged view of the control panel for this module is shown below in Figure 4.20. The panel displays all the parameters associated with a typical aggregate planning problem. The player is expected to enter the production quantities and workforce to estimate a profit for his aggregate plan.

**Figure 4.20: Control Panel for Aggregate Planning Module**
4.3.4 Challenge Module

The Challenge Module is a web-based multiplayer team activity where the students get a chance to apply all the concepts they have learned during the course of three learning modules. A virtual laptop supply chain is simulated and the whole activity is managed by the course instructor. Each game is identified by a unique GAMECODE. The game comprises of eight teams – two retailers, two OEMs and four suppliers. All eight teams are assigned a unique PASSCODE. The combination of these two codes forms the login for the teams.

![Control Panel for Challenge Module](image)

**Figure 4.21: Control Panel for Challenge Module**

The figure 4.21 above shows the control panel for the Challenge Module which can only be accessed by the instructor. All the data for challenge module is stored and managed though a
central MySQL database setup on the mechanical engineering department’s server. The instructor can use the control panel to setup a new game, upload the demand scenarios for the game and view the various data tables.

The figure 4.22 below shows the Contract Management Tool for the challenge module. Three buttons – “Propose”, “Accept” and “Terminate”, are provided on the tool. The teams can use the tool for proposing a contract, viewing the current proposed contract and finalizing (or terminating) a sales contract. All actions directly update the data on the central database. Note that only contracts between the OEMs and suppliers are allowed to be terminated.

![Contract Management Tool for Challenge Module](image)

*Figure 4.22: Contract Management Tool for Challenge Module*
Figure 4.23: Aggregate Plan Form for Challenge Module

The figure 4.23 above shows the Aggregate Plan Form for the challenge module. The two OEMs and the four suppliers are required to submit their respective production plans. This form allows them to submit their aggregate plans and also checks for any violation for constraints. Once all the contracts and aggregate plans are finalized and uploaded on the database, the instructor can use the main interface (Figure 4.24 below) for running the simulation and calculating the results. A supply chain is simulated using a particular demand scenario and profit margins for all teams are calculated. Figure 4.25 below displays the final results for the simulation in form of the players’ income statements.
Figure 4.24: GUI for Challenge Module
Figure 4.25: GUI for Challenge Module showing final income statement

The Challenge Module thus acts as an excellent application platform for students to get a feel of an actual supply chain with activities such as contract negotiation. Besides, it also allows the student to test their knowledge of supply chain in a dynamic environment. For the instructor, the module acts as an interesting testing platform with much more active student involvement.
5. CONCLUSION

Several researchers have examined and endorsed the efficacy of simulation games in education. However, actual use of such games for engineering education is practically nonexistent. What could be the reason behind this unawareness? Firstly, although there is acknowledgement for such games, traditional lecture-based education still scores over them. Games are still thought of symbols of entertainment and fun rather serious education and learning. Introducing games into engineering education and watching them replace the good old pedagogical techniques is something very drastic and naturally will need time to gain trust and prominence amongst academia. Secondly, up till now there has been a lack of any well defined methodology good enough to be taken seriously. All existing simulation games are hardly comprehensive and do not encompass all the qualities of a good educational game. Current educational games serve no clear purpose and are generally focused on one single concept.

The teaching methodology proposed in this thesis addresses this need and defines a new comprehensive teaching model for engineering education well suited for modern day students. Integrated problem solving, a virtual reality based environment and a progressive learning approach form the three pillars of the proposed methodology. Game developers in this field will have to integrate a good visual environment with clear and holistic course content in order to make the games most effective. While playing such games, students should be able to interrelate with the concepts they are taught and appreciate their practical significance. They will have to realize that it’s only when the student is able to transfer and apply the theoretical knowledge gained in such games in a practical real world scenario, that the game’s actual purpose will be served.
The new methodology spells a drastic role reversal for the instructors and students as compared to traditional pedagogy. This is more of a student centric method where no more ‘spoonfeeding’ of educational concepts will take place. Students will take control, be more independent and will have to be more responsible. On the other hand, instructors’ role will be that of promoters of education rather than agents. Students will act as the active participants rather than just blunt receptors of education [1].

It is the implementation of this methodology that has the potential to overcome the long standing issues that have plagued both engineering and STEM education. The future work regarding this proposed methodology primarily should be concentrated towards validating its benefits. Educational societies will have to shed their nonchalant attitude towards this methodology and pay serious attention to it given its apparent potential. Finally to harness its benefits to the fullest, more effort is needed in developing games such as iPPC and Supply Chain, LIVE [86]. This is just the beginning.
REFERENCES


[34] Hollocks, B. W., "The impact of simulation in manufacturing decision making", Management Systems Department, Bournemouth University, Fern Barrow, Pools, Dorset, BH12 SBB, UK


Harvey, R.S., & Sandom, C., Human Factors for Engineers, Institution of Electrical Engineers


Shaffer, J., Virtual Reality In Education, <http://www.newhorizons.org/strategies/technology/shaffer.htm#a>

Dewey, J., Experience and Education. New York: Kappa Delta Pi 1938


APPENDIX A - TECHNICAL FEATURES
Supply Chain, LIVE is a Windows based application compatible with all versions of Windows XP and Vista operating systems. It requires a minimum of 400 MHz processor, 96 MB of RAM and up to 600 MB of available hard drive space for proper functioning. A display resolution of 1024 x 768 high color 32-bit is also required. As with most modern applications designed in Microsoft’s Visual Studio, Microsoft .Net Framework Version 3.5 is a basic requirement for this game. Besides, MS Agent 2.0 control is required for the functioning of the Genie character. Both of these are embedded into the game’s setup file.

The programming was done on the Visual Basic .Net (Visual Basic 2008 / VB 9.0) environment, now commonly referred to as just Visual Basic. VB, being a high-level event-driven programming language, is relatively easy to program because of its in built graphical development features and an integrated development environment (IDE). With the integration of .Net Framework compiler, VB has evolved into a powerful object oriented programming language well suited for small scale applications such as Supply Chain, LIVE.

All the modules in Supply Chain, LIVE follow an object oriented design and revolve around two main objects, the player and the brand. Figure 4.22 below shows a simplified class diagram with the characteristics of the respective classes. Although the basic structure remains same for all the modules, the characteristics change according to their specific requirements. A supply chain in general consists of a complex network of suppliers, manufacturers, retailers etc… having similar characteristics. A well defined class structure is important for programming purposes as it enables better control and reusability of these characteristics.
Figure A.2.1: Simplified view of the class diagram
The Inventory Management module has two instances for the Player class, the player playing as a retailer forms one and the OEM supplying goods to the retailer forms another. Three instances are created for the Brand class denoted by the respective products the retailer deals in. These are laptops, desktops and HDTVs. Similarly, the forecasting module, having just one retailer dealing only with laptops throughout, has just one instance each for both classes. The Aggregate Planning module, where the player playing as the laptop OEM and manufacturing only one product deals with two retailers, has the respective number of instances.

The database for the Challenge Module was setup on MySQL/Ubuntu platform.
APPENDIX B – THE SUPPLY CHAIN GAME

Two laptop OEMs (original equipment manufacturers), Bell Inc. and Ultra Laptops, dominate the market. The laptops are sold through two retailers, Best Value Electronics and Pop Electronics. Demand during stock out is lost. The OEMs outsource two components, DVD drive and battery. There are two DVD drive manufacturers, Alpha Drives and Beta DVD, and two battery manufacturers, Longey Batteries, and Everlast PVT Ltd. All companies use TransMono for transportation of goods. TransMono charges a fixed $5,000 service fee for each delivery, plus $1 for each DVD drive or battery and $2 for each laptop delivered.

1. Retailer (negotiate contract with OEMs)

The retail prices for a Bell laptop and an Ultra laptop are $1,000 and $1,700, respectively. The inventory holding costs are $12 and $15 per month for a Bell laptop and an Ultra laptop, respectively. Operating expense (fixed cost) is $18 million per year. Monthly sales figures for the past 5 years are shown in the following tables.

<table>
<thead>
<tr>
<th>Year</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>904</td>
<td>902</td>
<td>1066</td>
<td>990</td>
<td>999</td>
</tr>
<tr>
<td>2</td>
<td>940</td>
<td>947</td>
<td>1003</td>
<td>1009</td>
<td>977</td>
</tr>
<tr>
<td>3</td>
<td>1074</td>
<td>865</td>
<td>1021</td>
<td>942</td>
<td>1004</td>
</tr>
<tr>
<td>4</td>
<td>959</td>
<td>975</td>
<td>971</td>
<td>1053</td>
<td>1013</td>
</tr>
<tr>
<td>5</td>
<td>1095</td>
<td>938</td>
<td>995</td>
<td>940</td>
<td>989</td>
</tr>
<tr>
<td>Year</td>
<td>2005</td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
<td>2009</td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>1</td>
<td>3173</td>
<td>2869</td>
<td>3694</td>
<td>3191</td>
<td>3240</td>
</tr>
<tr>
<td>2</td>
<td>2929</td>
<td>3453</td>
<td>2150</td>
<td>2247</td>
<td>3076</td>
</tr>
<tr>
<td>3</td>
<td>3071</td>
<td>2925</td>
<td>2648</td>
<td>3015</td>
<td>3778</td>
</tr>
<tr>
<td>4</td>
<td>2967</td>
<td>3397</td>
<td>2819</td>
<td>2705</td>
<td>2216</td>
</tr>
<tr>
<td>5</td>
<td>2437</td>
<td>2703</td>
<td>3136</td>
<td>3817</td>
<td>2984</td>
</tr>
<tr>
<td>6</td>
<td>2566</td>
<td>2883</td>
<td>2465</td>
<td>2267</td>
<td>2518</td>
</tr>
<tr>
<td>7</td>
<td>2951</td>
<td>2699</td>
<td>2473</td>
<td>3223</td>
<td>3249</td>
</tr>
<tr>
<td>8</td>
<td>3367</td>
<td>2549</td>
<td>3284</td>
<td>2498</td>
<td>2155</td>
</tr>
<tr>
<td>9</td>
<td>2997</td>
<td>3223</td>
<td>2571</td>
<td>3269</td>
<td>3410</td>
</tr>
<tr>
<td>10</td>
<td>3252</td>
<td>2640</td>
<td>3132</td>
<td>2697</td>
<td>3516</td>
</tr>
<tr>
<td>11</td>
<td>2685</td>
<td>2981</td>
<td>3008</td>
<td>3222</td>
<td>2888</td>
</tr>
</tbody>
</table>

Table 2: Sales figures of Ultra laptop at Best Value Electronics
<table>
<thead>
<tr>
<th>Year</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4862</td>
<td>5224</td>
<td>4805</td>
<td>4953</td>
<td>5164</td>
</tr>
<tr>
<td>2</td>
<td>5231</td>
<td>4992</td>
<td>4702</td>
<td>5005</td>
<td>4915</td>
</tr>
<tr>
<td>3</td>
<td>5211</td>
<td>4484</td>
<td>4761</td>
<td>5522</td>
<td>4753</td>
</tr>
<tr>
<td>4</td>
<td>4780</td>
<td>4847</td>
<td>4781</td>
<td>5244</td>
<td>4864</td>
</tr>
<tr>
<td>5</td>
<td>4677</td>
<td>4789</td>
<td>5005</td>
<td>5073</td>
<td>5067</td>
</tr>
<tr>
<td>6</td>
<td>5520</td>
<td>5997</td>
<td>5963</td>
<td>6453</td>
<td>6264</td>
</tr>
<tr>
<td>7</td>
<td>5112</td>
<td>6486</td>
<td>5768</td>
<td>6310</td>
<td>5827</td>
</tr>
<tr>
<td>8</td>
<td>4842</td>
<td>5026</td>
<td>5327</td>
<td>5129</td>
<td>5688</td>
</tr>
<tr>
<td>9</td>
<td>5211</td>
<td>4594</td>
<td>4649</td>
<td>5409</td>
<td>5546</td>
</tr>
<tr>
<td>10</td>
<td>5147</td>
<td>4836</td>
<td>4813</td>
<td>5086</td>
<td>5101</td>
</tr>
<tr>
<td>11</td>
<td>6443</td>
<td>6846</td>
<td>7056</td>
<td>7046</td>
<td>7015</td>
</tr>
<tr>
<td>12</td>
<td>7049</td>
<td>6744</td>
<td>7177</td>
<td>6632</td>
<td>7049</td>
</tr>
</tbody>
</table>

Table 3: Sales figures of Bell laptop at Pop Electronics

<table>
<thead>
<tr>
<th>Year</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>941</td>
<td>1013</td>
<td>1040</td>
<td>1131</td>
<td>803</td>
</tr>
<tr>
<td>2</td>
<td>1132</td>
<td>1161</td>
<td>912</td>
<td>893</td>
<td>1209</td>
</tr>
</tbody>
</table>
2. OEM (negotiate contracts with retailers and suppliers, determine monthly production quantity and workforce)

The material costs (excluding DVD drive and battery) for producing a Bell laptop and an Ultra laptop are $400 and $600, respectively. The labor hour required for producing a laptop is 1 per unit. A maximum of 160 regular time hours and 40 overtime hours are available each month. Workers are paid a monthly salary of $1,500 each no matter how many regular time hours they work. For overtime work, each worker is paid $14 an hour. The costs of hire and layoff a worker is $1,000 and $2,000, respectively. The inventory holding cost for a laptop is $10 per month. The inventory holding cost for a DVD drive or a battery is $4 per month. Operating expense is $3.6 million per year.
3. Supplier (negotiate contracts with OEMs, determine monthly production quantity and workforce)

The material cost for a DVD drive or a battery is $40. The labor hour required for producing a DVD drive or a battery is 1 per unit. A maximum of 160 regular time hours and 40 overtime hours are available each month. Regular time and overtime hourly labor costs are $9 per worker and $12 per worker, respectively. The costs of hire and layoff a worker is $500 and $1000, respectively. Each supplier has a manufacturing facility that can accommodate a maximum of 40 workers. Workers are paid based on the actual hours they worked each month. The inventory holding cost for a DVD drive or a battery is $3 per month. Operating expense at supplier is $1.2 million per year.

4. Assumptions

- Initial workforces at OEMs and suppliers are 0
- Initial inventory at retailers, OEMs, and suppliers are 0
- The cost of transporting raw materials to DVD drive and battery suppliers is absorbed by raw material suppliers
- No subcontract allowed

5. Contract Format

- Unit price with three tier quantity discount, e.g., $700 if not more than 1,000 units; $680 if between 1,000 and 2,000 units; $675 if more than 2,000 units
- Penalty for each unit of demand that cannot be met, e.g., $100 per laptop (if Pop Electronics orders 2,000 Ultra laptops but Ultra can only deliver 1,800, Ultra will pay a penalty of $20,000 to Pop Electronics)
- The part who pays transportation cost (either buyer or seller)
- Monthly order quantity