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Web-Based Supply Chain Simulation: an Integrated Approach

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WEB-BASED SUPPLY CHAIN SIMULATION: AN INTEGRATED APPROACH

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Abstract

This is an era marked by rapid technology development in all different educational arenas. Alongside this growing demand of technology, learning process is getting new forms and hence traditional teaching approaches tend to struggle and lack the requisite qualities to meet new generation expectations. In third level education, this problem is increasing in magnitude and new dimensions, especially when it comes to teaching difficult subjects such as supply chain management. Understanding the complexity of supply chain networks and how to manage them create a considerable level of difficulty for students and professionals. Collaboration between supply chain members is now recognised as an important strategic factor in creating a solution to the complexity of the supply chain system. New technologies are beginning to bring a huge transformation into teaching delivery methods. This paper presents an integrated web-based simulation framework that supports learning supply chain concepts and challenges. Simulation-based learning environment allow participants to examine various management strategies without real disruptions to the current system. Using supply chain simulation creates a vibrant experience and a better understanding to the impact of uncertainty and risks within supply chains. Integrating web technologies to simulation has added an edge to the learning environment with the friendly graphical user interface.

Keywords: Simulation-based learning, web-based technologies, supply chain management.

1 INTRODUCTION

Never has there been a better time for educational institutes to exploit the advances in information communication technologies and other technological breakthroughs. Especially the relationship between teaching and learning and the bridging of the theory/practice gap for college graduates entering the workplace. Instructional technologies such as; overhead transparencies, slides, videotapes and computer programmes play an important role in the bridge between learning and teaching[1]. However, over the past few decades, these technologies have matured and individually they are not a recognised stimulant for today's more digitally orientated students [2, 3]. To help stimulate this new era of virtual students, there is huge scope for the use of simulation as an aid to these learning techniques, although there are few if any examples in literature. Apart from maybe in medical [4], engineering [5] and science schools, simulation modelling is one technological advancement in recent years that has still to be embraced by educational institutes [6].

There has been an increased development of simulation software packages that have increased simulation capabilities [7]. Business modules, including supply chain management, are one area that these enhanced capabilities can be most effectively utilised. Understanding the magnitude and complexity of supply chain networks and how to manage them creates a considerable amount of difficulty for students and practitioners alike. Supply chain experimentation and decision making in the real world can have detrimental effects (such as distorted and amplified supply and demand) on companies when they go wrong [8]. Collaboration between supply chain members is now recognised as an important strategic factor in decreasing the impact of poor supply chain decisions. In the academic world, visualising and understanding the size and complexity of supply chains has always been an issue. Using computer simulation coupled with web-enabling technologies, a detailed, animated and generic supply chain simulation framework can be developed to incorporate many areas of learning undertaken by students in relation to the supply chain management. Experimenting/playing on the simulation models allow the students to examine quantitatively the impact of changing critical factors such as capacity utilisation and queuing times on the performance measures within the supply chain. Web enabling applications also allow students to access online versions of the simulations without the necessity of purchasing expensive simulation software.

In this paper, an introduction into third level education and its challenges and innovations, Section 2, is followed by a detailed description of supply chain management, Section 3. Using this as a foundation, a detailed simulation-based learning framework integrated with web-enabling technologies is developed and presented in Section 4, before a conclusion is made in Section 5.

2 THIRD LEVEL EDUCATION

It is recognised that the future economic success and social well-being of countries such as Ireland is closely linked to the level of knowledge and skills of their populations [9]. For Ireland's knowledge economy, the effectiveness of third level education (TLE) is extremely important to obtaining the levels of knowledge and skills required to capitalise on this recognition. For this reason, there has been an increased emphasis put on higher education by Irish governments over the past few decades, resulting in a large increase in TLE student numbers (Fig. 1) [10]. In particular, government incentives such as; the abolition of college fees in 1996 [11] and the "Charting Our Education Future" white paper in 1995 [12] laid the foundations for the knowledge economy. However, with such a high level of investment in TLE, it is critical that the challenges within the teaching/learning relationship are understood and addressed to ensure that college graduates make a successful and optimised transition into the workplace.

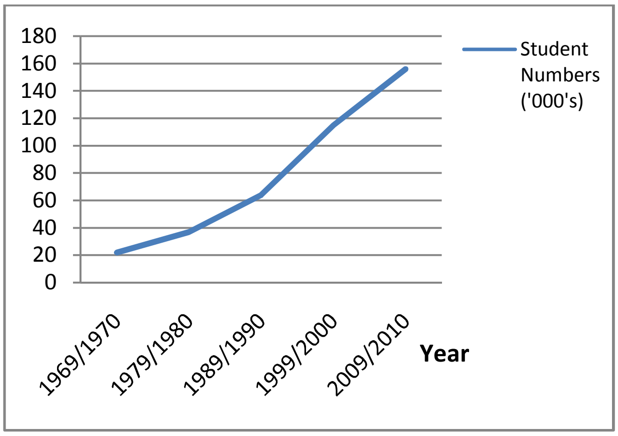

Figure 1. Enrolments of full-time students in Institutions aided by Department of Education, Ireland

2.1 Challenges to the Teaching Learning Process

The relationship between TLE teaching and learning hangs on a delicate balance between a student's willingness and ability to learn and a lecturer's willingness to create an effective learning environment. Maintaining this balance can make all the difference to students' learning experiences in TLE [13]. To do this effectively, there was a need to move away from the more traditional methodologies used in teaching TLE. In traditional teaching, the success of college graduates was often predicted by the amount of knowledge students had accumulated during their degree [14]. This suggests that a lecturer in the traditional setting informed students instead of transforming them [15] and the traditional university course was characterised by its lack of flexibility in terms teaching content [16]. Traditionally teaching was fundamentally thought about in relation to information transfer between teacher and student only. This learning process was typically believed by past academics to consist of a knowledgeable educator on a particular topic, who constructed and communicated knowledge on such topics to learners using the common instructional technologies of the day; books, articles and classroom lectures [17]. This form of "rote learning" was suggested to be outdated and aversive as early as the studies of Dr. B. Skinner in the 1950's [18]. As early as the late 1930's it was argued that effective education is based on the interaction of an individual's external and internal environments, also known as constructive learning [19]. Learning activities in constructivism are characterised by active engagement in the classroom, collaboration with others, inquiry, reflective thinking and problem solving [20] [21].

During the past 30 years, TLE has been experiencing a revolution. The objectives of third level institutes have changed. Memorising facts and figures are now recognised to be less important than developing knowledge based skills for; problem-solving, interactive team work and life-long learning [14]. The introduction of the learning pyramid has instilled a new focus on the way teachers interact with students in relation to the retention of what is being taught [22]. In brief, the pyramid suggests that over 90% of all learning retention is achieved by participants who practically use theory learned immediately, and then teach it back to each other in group work sessions and presentations [15]. This is in contrast to the 5% retention rate given to the traditional rote learning process of the class lecture. The foundations of the framework developed in this paper are built on the concept of this pyramid.

2.2 Innovations in the Teaching Learning Process

Learning is an iterative process loop. The learning loop is a process of ongoing refinement of a conceptualise-construct-identify pattern, with dialogue playing a central role in each stage [23]. This process was articulated in an earlier study by [24] who places the iterative sequence of the ideal teaching and learning process in a four-stages model shown in Table 1. An important emphasis is put on key elements of understanding the practical aspects of what was learned in theory. That is; discussing what was learned; interaction within the class on what was learned; adapting this knowledge for a better understanding; and reflecting on what the learning outcome achieved to improve the learning process. Active learning as discussed by [25] and [26] also associates the same theme of a more interactive, collaborative and cooperative approach to learning. Problem based learning (PBL) is another technique that also allows the student to interact with a theoretical problem in a more practical real life way using the ideology of active learning, especially in medical schools [25, 27].

Table 1- Characteristics of the ideal teaching/learning process [24]

Discussion	Between teacher and learner at the level of descriptions
Interaction	Between the learner and some aspect of the world defined by the teacher
Adaptation	Of the world by the teacher and action by the learner
Reflection	On the learner’s performance by both teacher and learner

There have been many technological innovations in recent times to aid this. Over head projectors and PowerPoint slide presentations are the most commonly used. But there also more complex methods such as distance learning, online and web-based learning and a combination of information technology with traditional teaching called blended learning. At its basic level, blended learning is the integration of face-to-face classroom learning experiences with online learning experiences, [28]. Wireless keypads [29] and audience response systems (ARS) or clickers [30] have also aided in the transformation of the third level lecture. The use of simulation technologies is becoming an accepted and recognised method of teaching theory with a practical edge. Medical, nursing and engineering schools have been at the forefront in advancing this learning process [31, 32]. The potential for simulation to be utilised in business faculties is encouraging, especially in areas of management such as supply chain management.

3 SUPPLY CHAIN MANAGEMENT

Even though the concept of supply chain management (SCM) was first introduced in early 1980 by Oliver and Webber, cited in [33], it was not until the mid 1990’s that it came to prominence. As a management philosophy, it is a very vast concept, with many interpretations and definitions. SCM can be defined as the management of upstream (suppliers) and downstream (customers) relationships in order to create enhanced value in the final market place at less cost to the supply chain as a whole [34]. The basic supply chain in Fig. 2 illustrates very effectively the relationship between upstream and downstream partners; information (the order cycle) flows both directions, downstream is the flow of material to the end user, whereas upstream is the flow of capital to finance the chain. It shows a strategic collaboration between business partners to commit to close supply chain relationships to bring greater value to the end consumer and their customers for the least possible supply cost [35].

3.1 Supply Chain Challenges

At its basic level a supply chain is made up of multiple actors, multiple flows of items, information and finances and is sometimes described as looking like an uprooted tree [36]. Each network node has its own customers’ and suppliers’ management strategies, partnerships, demand arrival process and demand forecast methods, inventory control policies and items mixture [37], with many challenges to overcome. There are many challenges to overcome at all strategic levels of SCM, including; complexity, uncertainty, risk, resilience, visibility, and cost to name a few. This paper will focus on one of the most important and difficult to teach to TLE students; supply chain complexity.

Complexity is a key managerial issue that SCM needs to address, especially in terms of operational processes and manufacturing strategies [38]. The complexity of most supply chains makes it difficult to understand how the actions and interactions of multi-tier supply chain partners influence each other [36]. Understanding supply chain uncertainty and supply chain visibility are essential in strategically measuring and teaching such influences.

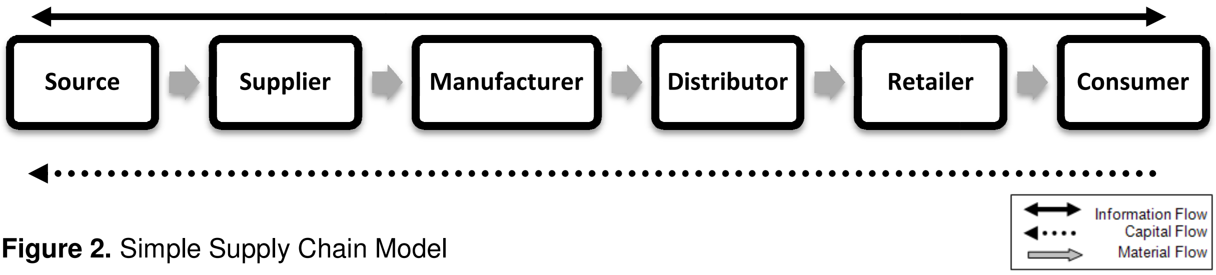

Figure 2. Simple Supply Chain Model

3.1.1 Supply Chain Uncertainty

Supply chain uncertainty is a key issue known to impact the effectiveness of a supply chain, most recognisably the uncertainty between supply and demand [39]. Examples of uncertainty in the supply chain process include; demand quantities, sales orders, delivery/arrival time, suppliers' lead time and defective rate of received products [40]. Dr Andrew Grove, past president of Intel suggested that research into supply and demand at the company found that they were in equilibrium for just 35 minutes in 10 years [41-43]. The complexity triangle developed by [42] is a framework that can explain such variances and uncertainty in the supply/demand relationship. The triangle explains that there are three interacting yet independent effects that cause the dynamic uncertain nature of supply chains. They are; deterministic chaos, parallel interactions and demand amplification. These effects are similar to the uncertainty in decision making situations described by [44], primarily when the decision maker does not know definitively what to decide because of a lack of information, process knowledge, behavioural impact and controls. Visibility, through partnerships with key suppliers and customers may reduce uncertainty and risk within the supply chain [44].

3.1.2 Supply Chain Visibility

As illustrated in Fig. 2, information and material flow, or the order cycle, plays a very important role in the effectiveness of SCM, both upstream and downstream along the supply chain. This order cycle is often referred to as pipeline time, and confidence in the supply chain is weakened if the pipeline is too long [45]. Visibility of material and information flow is associated with the length of the pipeline time, and the key to improved supply chain visibility is shared information along the supply chain [45]. Collaboration along the entire supply chain is needed to create a transparent, visible demand pattern that paces the entire supply chain [46].

3.2 Supply Chain Collaboration

Through collaborative links stronger relationships will form within the supply chain, that in turn will drive competitive advantage for the supply chain partners [47]. The days of poor co-operation, where suppliers are kept at arm's length, much like the traditional relationship outlined by [48] are gone and a new wave of collaborating firms are being developed on high levels of; trust, commitment and information sharing [47]. The process of moving through the relationship process to collaboration can be seen in Fig.3.

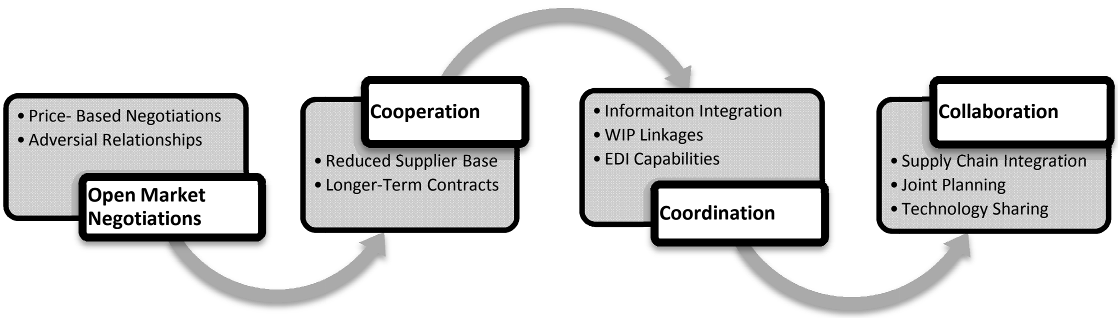

Figure 3. Transition from Open Market Negotiations to Collaborative Partnerships

SCM is about the management of relationships across complex networks. Successful supply chains will be those that are governed by a constant search for win-win solutions based on, collaboration, mutuality and trust [49]. There are four distinct relationship types outlined as being most effective for a win-win relationship [48], depending on the level of strategic collaboration need; Traditional; Opportunistic Behaviour; Strategic Collaboration; and Tactical Collaboration.

4 SUPPLY CHAIN SIMULATION

Today's TLE students are of the virtual age, were online multi-player games, virtual reality and simulations are a part of everyday life, making gaming and simulation a very important catalyst in the learning process [32, 50]. A supply chain is stochastic and dynamic in nature, resulting in high levels of variability and uncertainty. The capabilities of simulation software to replicate uncertainty are high, mainly through discrete event simulation as it is capable of manipulating the variability and uncertainty of a system [51]. In spite of this, there have been very few examples of SCM simulation theory being used in TLE. The most popular being the beer game introduced by MIT in 1960 as an exercise in industrial dynamics [52]. Some academics say that the medium of games have been under utilised by educators, with institutes focusing on negative social consequences while ignoring the important potential of gaming and simulation as teaching aids [53]. Little has changed since the beer games introduction. There have been some advances in simulation education such as; van der Zee and Slomp's assembly line simulation game [31] and the activity-based-costing (ABC) flash simulator game developed by McKee and Lantz [54]. Although very effective in visualising and simulating the fields of production processes and costing they do not have the scope to incorporate all areas of a supply chain. Simulation has huge potential to be a very effective tool in teaching the practical operations of SCM. Fig. 4, adapted from [55], illustrates how simulation can be used as a link between the active learning of constructivism and the hands on experience of real-life practice.

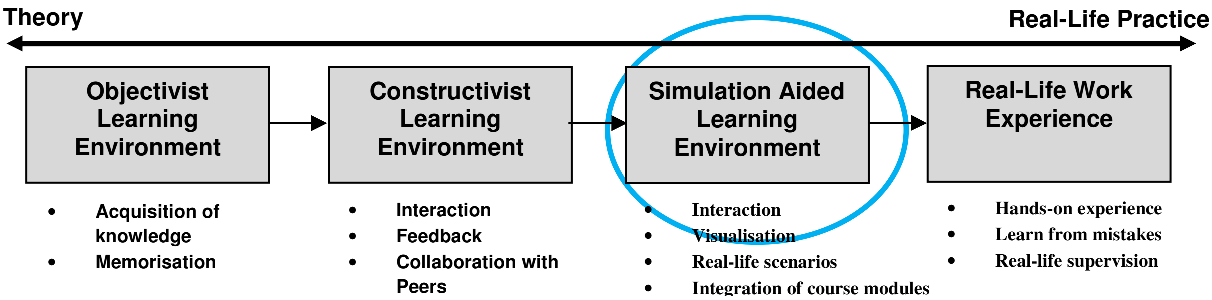

Figure 4. Simulations Link between Theory and Real-Life Practice

4.1 Teaching Supply Chain Management using Simulation Technology

The central theme through this paper has been investigating the potential of using interactive simulation technologies to facilitate learning concepts of supply chain management. The advances in simulation educational innovations such as the beer game and ABC simulator have been found to be very effective in aiding teaching of certain tiers of a supply chain network such as distribution, material movement and costing. However, they lack the fundamental ability to effectively visualise and demonstrate the operations of the whole supply chain; from the source of raw material to the delivery to the end consumer (Fig. 2). Section 3 has highlighted the importance of collaboration and visibility along the supply chain and these advances do not incorporate this, although there are some simulated supply chain models developed that incorporate a broader scope of SCM, such as; SCM decision support tool [37] and the object-orientated framework [56] for simulating supply systems. But it is important to note that these models were developed as analytical decision making tools for supply chain managers and do not have the required interaction, animation, or academic attributes that would stimulate the mind of a TLE student. To incorporate the entire supply chain in one interactive teaching aid, a simulation-based learning framework was created. Taking the importance of supply chain collaboration into consideration, the model developed for the purpose of this research simulates the relationship between two key members of the supply chain, a manufacturer and its supplier.

4.1.1 Supply Chain Case Study

Up until recent years, understanding the potential and nature of the manufacturer/supplier relationship was limited. Relationships were traditionally transactional focusing on cost, delivery time and quality alone [57]. As section 3 highlights, supply chain complexity is decreased with visibility and collaboration along the supply chain, and the overall pipeline time shortens increasing supply chain confidence. To demonstrate the effectiveness of the simulation-based learning framework in teaching SCM complexity, two key supply chain members; a manufacturer and a first tier supplier were modelled, simulated and measured.

Using hypothetical, yet accurate input data, including; forecasted and actual sales figures, production process capacity, product specifications, lead-times and product costing the relationship between the two supply chain members were studied. Equations, management strategies, statistical analysis and other management science techniques that SCM students will learn in their degree were integrated into the model results to illustrate (Fig. 6) the impact of input and process decisions on the model outputs, which include warehouse capacity utilisation, cycle throughput time and queue lengths. The end objective is for the user to practically understand the complex relationship between the manufacturer and supplier, and how the impact of their management choices and input decisions affects the efficiency of the partnership.

4.2 Simulation-Based Learning Framework

Prior research by the authors of this paper resulted in the creation of a simulation-based learning framework [58]. Using detailed conceptual models of a supply chain, the framework was developed to assist in the future creation of an actual simulation-based teaching aid to TLE SCM lecturers. The whole framework depended on modelling the basic concepts and theories of SCM and integrated them into a powerful simulation tool. Designing and implementation process of this project involved computer engineering and supply chain management experts to achieve the required aspects of the system. The implementation of the framework can be divided into two stages. The first stage was the design and implementation of a simulation model for SCM using a powerful simulation tool [58]. The demonstrated framework for the first stage consists of 5 main categories to achieve a complete and practical understanding of a global supply chain. They are; (1) SCM variables; (2) hierarchical conceptual modelling; (3) simulation; (4) optimisation; and (5) SCM decisions. The second stage of web-enabling applications developed for this research (Fig. 5) consists of two parts; (1) communication bridge; (2) interactive graphical user interface. The research in this paper has allowed the transferring of those results to the next stage, and is achieved by the communication protocol layer. The final stage which acts as the interface stage with its ability for adaptation can be used to produce different type applications (standalone, web-based, network, Educational game, etc.).

4.3 Web-Based Application

As section 4.1.1 noted, a simulation model has been built to highlight the supplier/manufacturer relationship of a supply chain. Creating an efficient usable interactive interface has been taken into account during the design and implementation process for the system. In the analysis and design stage of the conceptual model, the effective key variables were extracted and used as controlling variables in the system to enable the student to practice and understand the consequences of changing these variables on the system. The produced data from the simulation tool was transferred to the integrated development environment (IDE) through the communication protocol layer.

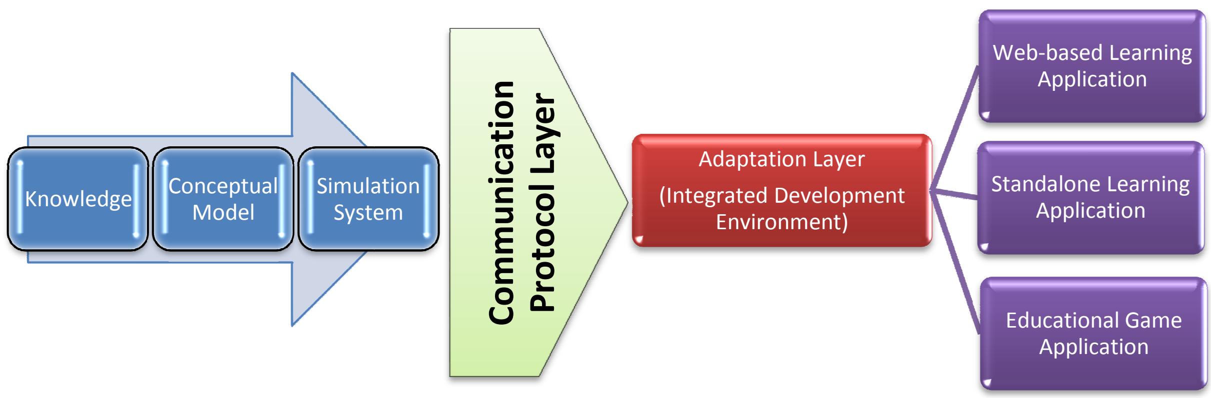

Figure 5. Web Enabled Simulation-Based Learning Framework

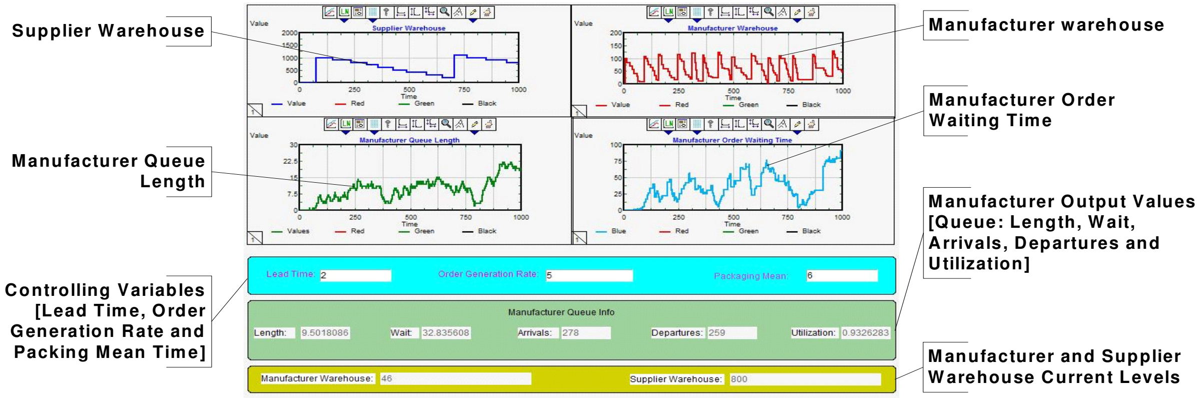

Figure 6. Simulation Model Results

Using the IDE capabilities, the simulation model has been transferred to a new dimension which combines the huge capabilities of both, the simulation tools and the programming tools. By choosing a suitable IDE, the final software product can be built as a web-based application. Enabling and integrating of the previous technologies produced software training and learning system capable of being used as a web-based environment.

4.3.1 Communication Bridge

Binding between the first stage results and the second stage interface building requires a suitable communication protocol. This protocol has been demonstrated in the bridge layer. The main idea of the protocol is to avail a common data exchange space to be accessed from both sides. The responsibility of the simulation tool is to pass simulation results probed by certain simulation tool components to the shared space and check for any instructions data in the same space through I/O stream channel. On the other side, the integrated development tool sends instruction data to the simulation tool and reads the simulation results from the shared space through suitably programmed routines and I/O (input output) channel. The building rules of this protocol demonstrate two important advantages; simplicity and flexibility. Simplicity of this protocol gives a good chance for it to fit between different simulation tools and software development tools. Flexibility has been achieved by assigning programmed routines to the protocol which adds a level of controllability to the complexity and options of the protocol.

4.3.2 Integrated Development Tool

The integrated development tool used is one of Adobe development tools. It is considered as an Integrated Development Environment (IDE). It owns an efficient GUI with high level of usability and controllability. An important part of this tool is the pre-developed components which contain a wide range of useful operations. These components coupled with the programming ability in the tool helps in expand the usability of the tool to various extents. Building software system for the sake of learning and education involves needs for efficient interactive interface, good look and feel, flexibility in design and usability, dealing with databases and applying new designed and programmed functions and structures tailored according to the knowledge field. Integrated development tool is highly recommended to achieve the previous targets. Nevertheless, integrated development tools have the capability of producing web applications and handling of network communications which raise the designed applications to the stage of group communication which is one of the important aspects in the learning and education process [59]. Designing and implementation of the first stage followed by the second stage produces a learning application with a degree of adaptability. The adaptability can be verified through the adaptive layer (Integrated Development Environment). This layer controls the aspect of the produced application if it will be web application, game project, standalone training system; network shared learning application or any other category application. Using efficient development tool to produce the final applications gives the ability to analyse, interpolate and extract information automatically from the results through programmed routines.

5 CONCLUSION

The complexity of SCM theories and concepts imposes considerable challenges in the education process for TLE students. Traditional teaching methods alone are no longer able to create an effective learning environment. Research has shown that interactive and visual aids integrated into the learning process increases knowledge retention. Due to its wide subject area and stochastic nature, this paper proposed a framework to apply learning and education theories in SCM field. Understanding the complexity of supply chain networks and how to manage them create a considerable level of difficulty for students and professionals. Collaboration between supply chain members is now recognised as an important strategic factor in creating a solution to the complexity of the supply chain system.

Today's TLE students are part of a new virtual generation where simulation and virtual reality are part of everyday life. Exploiting this, the developed framework, a simulation based learning technique has been designed to attract the attention of the TLE students. Basics and main SCM concepts have been taken into account while designing and building the system. An efficient interactive graphical user interface with high level of usability and attraction has been designed to facilitate dealing with the system. Combining two different technologies (modelling and simulation tools and IDE) assigns efficient aspects to the proposed framework. Through the communication bridge between the simulation layer and the programming layer the designer can achieve multipurpose output application, educational games, web-based applications, standalone training environment, etc. Integrating an IDE in the framework opens door for efficient programming features, descent and usable attractive interface, network and internet application deployment, high level of controllability and processing over the system and professional database communication protocols. Using this system, students can practice the impact of changing variables on the system without making any changes to the real system and see the result in an attractive way. Through this system, students can work in groups which improve their communication skills. The implemented system can accept an integration of different optimisation techniques as a future work to enhance supply chain controllability [60].

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