The Use of System Dynamics Simulation Models in Project Management Education

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Abstract

This thesis explores the impact of using System Dynamics (SD) as a simulation tool to help learners understand complex, dynamic concepts in project management education, and specifically with the learning of the theory associated with Earned Value Management (EVM). SD simulation models have been used widely but mainly in business contexts to support managers in the decision making process. However the application of SD in the field of project management education has been limited and particularly in terms of assessing its potential impact to help improve learners' skills and understanding about project management concepts.

'Projects' are considered to be complex information feedback systems, characterized by causality and underlying dynamic relations between multiple variables, and the ability of junior project managers to apply and experience higher practical skills in the management of these complex systems presents a real challenge in the higher education context. The ability of SD to simulate the behaviour of a system, to reveal the underlying relationships, and to help visualize its dynamic changes over time, makes SD a potential modelling tool to help supporting the learners in the project management education area. This study sets out to evaluate the use of SD in an instructional context to help postgraduate project management students to visualize and to more understand the complex dynamic relationships in the concept of EVM, a topic that features significantly in project management education.

In this study, SD was deployed to teach EVM through a series of computer based models to visualize changes of multiple interacting variables over time. The SD simulations were evaluated and improved in a series of pilot and formal studies. In an experimentally controlled study involving 46 students, EVM content was delivered with SD simulations and using traditional methods respectively. Results, both quantitative and qualitative, demonstrated a positive impact of SD on the learning of the EVM concept. Recommendations of further work to deploy SD in the delivery of complex project management content and other challenging topics, with wider pool of learners are discussed.

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Finally I would like to dedicate my work to the memory of my mother, and my family.

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List of Abbreviations

Agent Based Simulation (ABS)

American National Standard Institute (ANSI)

Body of Knowledge (BoK)

Capability Maturity *Model* (CMM)

Critical Path Method (CPM)

Discrete Event Simulation (DES)

Earned Value (EV)

Earned Value Management (EVM)

Graphical Evaluation and Review Technique (GERT)

Human Computer Interaction (HCI)

Multiple Choice Questions (MCQs)

Project Evaluation and Review Technique (PERT)

Project management (PM)

Project Management Institute (PMI)

Project Management Book of Knowledge (PMBoK)

Project Management Book of Knowledge guide (PMBoK Guide)

Projects in Controlled Environments, version 2 or shortly (PRINCE2)

Planned Value (PV)

SIPOC (Supplier – Input Process – Output – Customer) diagrams

System Dynamics (SD)

The Institute of Electrical and Electronic Engineers (IEEE)

Voice of the Customer (VOC)

Chapter 1 Introduction

1.0 Overview

This thesis sets out to explore the benefits of using System Dynamics (SD) in the field of project management education. Project management situations are complex, comprising multiple dynamic interacting relationships, encountering time delays between actions and consequences that are in turn interacting with further inputs in a non-linear way. All of these features make it difficult for learners to understand and develop skills that deal with such situations, using only snapshots of static knowledge and case studies, without complementing this with practical experiential learning aids.

Developing skills in a complex dynamic business education topic is a real challenge (Quadrat-Ullah, 2010). With the case of project management, the existing curricula address the topic in a fragmented way, so we can find each sub area is being addressed in isolation from other areas, for example: project finance, project human resources and project scheduling are being taught in different separated functions and chapters. This fragmented way of delivery is hardly preparing the students to develop proper models or strategies for real business world that connect between these areas (Sterman, 2000; Lainema, Nurmi, 2006; Quadrat-Ullah, 2010).

Simulation can support the learning of a complex dynamic field through the experiential learning environment that it offers (Burcu, et al., 2010; Quadrat-Ullah, 2010; Shtub, 2013), SD as one of the simulation techniques that provides this experiential learning environment has been rarely investigated empirically (Bravo, et al., 2009; Quadrat-Ullah, 2010); this is why, this study focuses on exploring the impact of using SD simulations on the project management teaching.

In order to explore the impact of using SD on helping learners to understand complex project management features, it is important to define what is meant by the term ‘complexity’ and what distinguishes a topic as a complex one.

1.1 Complexity

The word complexity is usually used as an attribute of natural or living systems that surround us everywhere, it explains a condition(s) where multiple, interconnected elements are combined into sub-systems, which work together in dynamic, non-linear and unpredictable ways (Forrester, 1961; Phelan, 2001; Sterman, 2000).

Complexity rather than being the exception is the norm, and as an idea, it is not limited to one specific field or science, but exists across the whole range of natural, social or engineering sciences. The challenge of understanding complexity is usually compounded by the structured approach that is so often used to handle the unstructured systems and situations. This approach is usually about simplifying and breaking a system down into smaller pieces or components. This is the approach of reductionism that entails reducing the system into parts in order to analyse it. The challenge with this approach comes from losing the properties that exist as a result of the integration between these parts and before breaking it down (Mittelstrass, 2014; Richardson, 2004; Wolinsky, 2014).

For example in biological systems, understanding the cell behaviour and function within multi-cellular organisms will not fully explain the emergent properties and the behaviour of a whole organism and its physiology. Likewise, in dynamic markets, simply focusing on quantity and price will not be sufficient to understand the profitability. Similarly, with a topic like project management where change is vital to the success of different projects (Shtub, 2012) a systemic approach is needed in project management education which is not confined to looking at the broken elements of the project, rather it takes into account a larger number of interactions among the internal elements and between the systems itself and its external surroundings. Looking at things from systemic or holistic approach complements the reductionist approach, it looks at the systems as a whole, and not only as a collection of parts (Auyang, 1999; Michael, 2001). The same concept could be applied in the process of teaching in general, and in teaching PM in specific, as introducing the project's components in different separated chapters, without giving the learner the opportunity to practice the behaviour of the whole project structure due to this level of integration, will lead to missing the foreseen behaviour of the whole project due to this level of interactions, which will consequently affect the learners' ability to understand beyond the theoretical basic information about the topic.

1.2 System Dynamics

In systems paradigm, there are many approaches that contribute to some kind of understanding about complex systems. System Dynamics (SD) is one among these approaches, and is characterized by the ability to visualize the governing dynamics, cause and effect of the relationships in a system, and exploring different behaviours or scenarios of the whole system. In complex project management scenarios, where project managers need to understand and respond to dynamic changes, the analytical and predictive properties of SD could provide the project managers with a powerful exploratory tool. However, the applications of SD in project management education today are limited, assessing its impact on learning based on empirical investigations are more rare (Quadrat-Ullah, 2010), this is why this study is aiming at contributing to this area.

1.3 Overview of System Dynamics

System Dynamics (SD) is a computer based approach in policy analysis and design of any dynamic systems that are characterized by interdependence, mutual interaction, information feedback, and circular causality. SD use diagrams to visualize specific systems or the scope of interest (Uzzafer, 2013). These diagrams usually include elements of feedback, accumulation and time delays which help in visualizing how the interrelated variables are affecting one another. In order to help analyzing and visualizing the system, a causal loop diagram (CLD) is used as a visual tool that represents the interdependencies and the feedback between the system's variables. It consists of a group of nodes that represent the system's variables, and a group of links for interconnecting these variables. These links could be labeled with a '+' sign for positive relations, or with a '-' sign for the negative relations.

In addition to CLDs, there is another technique called the stock and flow diagram (SFD), used to further create a business prototype of the system. It allows exploring the system's behaviour and testing the effect of changes to its structure and the policies governing its behaviour along with the mathematical expressions that explain the governing rules. The stocks are represented by a box, to represent a part of a system whose value at any given instant in time depends on the system's past behaviour. The flow represents the rate at which the stock is changing at any given instant, either through flow into a stock (causing it to increase) or flow out of a stock (causing it to decrease) (Burns, 2001), more details about CLD and SFD will come in section 2.4.2.

The feedback concept is at the heart of the SD approach. Diagrams of information feedback loops and circular causality are tools for conceptualising the underlying relations. This feedback loop exists when information resulting from some action travels through a system and eventually returns in some form to its point of origin, potentially influencing the future action. If the tendency in the loop is to reinforce the initial action, the loop is called a 'positive' or 'reinforcing' feedback loop which are sources of growth or accelerating collapse; if the tendency is to oppose the initial action, the loop is called a negative or balancing feedback loop that can be variously characterized as goal-seeking, equilibrating, or stabilising processes. Combining the reinforcing and the balancing circular causal feedback processes can generate all the manners of dynamic patterns in real life scenarios. Using these symbols to explain the system behaviour will be discussed in section 2.4.2.

1.4 System Dynamics Applications

System Dynamics has been widely exploited as an approach for understanding complex systems. The development of its modelling and simulations are various and could be found in numerous business and domain areas, for example:

- In Economics: There are SD models that examine the economics of rural areas and how certain policies can affect the employment and the population dynamics. There are other models that explore the workforce and the job market dynamics or to assess the economic impact arising from disruptions in the energy, telecommunications and labour market (Shapira, 1971; Wei, 1998; Yamashita, 2011; Ansari, Seifi, 2012),

- In Climatology: There are SD models that can simulate the carbon circulation and its impact on the climate change, and analyse the impact of emissions trading schemes on the national greenhouse gas footprint (Huerta, et al., 2011; Akpinar, Ali, 2010; Cavana, Adams, 2010),
- In Transportation: There are SD models that analyse the threats of adapted strategies on the sustainable transportation systems, and there are models that analyse the impact of transportation infrastructure investment on tourism development (Armenia, et al., 2010; Jiang, et al., 2010),
- In Education: There are SD models in primary, secondary, and high education, and are implemented in different subjects including physics and maths and others. For example, there are models used for helping students to understand the concept of acceleration focusing on the time factor, or models that are being studied from educational prespective and analysing its imapct on the learning competencies. (Hopkins, 1992; Alessi, 2000; Forrester, 2009a, 2009b; Schaffernicht, Patricio, 2010).

In general, SD usages and applications could be seen from different point of views and in terms of its purpose, so applications could be used as a domain-specific simulation tool for experts or modellers, or as an educational technique within any of the previously mentioned topics including the project management field. This will lead to further detailed discussion about the SD applications in the field of PM, to be tackled in the following section.

1.5 System Dynamics and Project Management Education

To date, the applications of System Dynamics in project management training and education are various, some of them are with the purpose of targeting the managers' decision-making process, and others are aiming at teaching system thinking basic concepts. The following will present samples for these applications:

- Lessons learned from modeling the dynamics of software development (Abdel-Hamid, Madnick, 1989), this presents a paradigm shift for the study of software PM that is relied on the feedback systems principles of system dynamics,
- The impact of goals on software project management: An experimental Investigation (Abdel-Hamid, et al., 1999) through which an analysis is being discussed about how goals can affect the managerial decision behaviour,
- Evaluation of the use of SD simulations in project management, and assessing the basic dynamics of R & D projects (Rodrigues, Bowers, 1996; Barros, et al. 2002; Pfahl, et al., 2003; Lyneis, Ford, 2007; Uzzafer, 2013; Nasirikaljahi, 2012)
- Monitoring and assessing projects' cost-time tradeoff (Love, et al., 2002; Zawedde, Williams, 2013)
- Evaluating policies and quality assurance rework in software development projects, investigating agile methods (Glaiel, et al., 2013)
- Assessment of SD in systems thinking skills in project management (Pfahl, et al., 2003), in this paper the focus was given mainly on assessing the system thinking skills and the level of understanding the behaviour change over time, feedback and causalities.
- Monitoring the rework cycle in projects and its recursive impact (Cruz, Eduardo, 2014; Rouse, 2012)

In summary, there are various SD simulation based models that exist in the field of project management education for postgraduates. Most of these models are mainly used as systems-thinking tools or models to explain the overall system's complex behaviour and to capture the decision making process, rather than a learning technique. This implies that there are significant opportunities to explore the use of SD in project management education and to explore on ground its impact on the learning process.

1.6 Study Background

In 2007, Egypt launched a strategic initiative (AT Kearney, 2007) to boost its competitiveness and to increase the number of job opportunities in the industries of offshoring and outsourcing. A key goal in this initiative was to assess the Egyptian talent pool that is needed to support the ICT offshoring and outsourcing national strategy at that time. The initiative relies on screening the HR needs of the local and the multinational industry players, and assessing the existing skills that are developed by the governmental and the private Egyptian universities. The study came up with a set of recommendations and actions that are needed to increase Egypt's competitiveness on the global map of offshoring and outsourcing. On top of the recommendations, there was a specific highlight on the need to increase and better prepare the number of qualified managers, by looking at the existing programs, curriculum, and the different attracting packages.

One of the national projects that was implemented in collaboration with European Union (EU) at that time, was a project called "Middle-Management Enhancement through Systems Thinking Skills". The project was set out to improve the decision-making process using systems thinking and cybernetics for a group of middle managers at the Suez Canal Authority. As a teaching assistant in this project, responsible for the development and delivery of materials in systems thinking concepts including 'systems thinking', 'cybernetics' and 'system dynamics', it was clear that the middle managers who were totally new to these topics enjoyed this different approach and were able to apply the theory to their management practices.

In parallel, and as a lecturer working in the field of Information Technology training focusing on the area of database related technologies and IT project management at the Institute of Information Technology (ITI) http://www.iti.gov.eg, Cairo, Egypt. It was evident that project management students faced significant challenges when it comes to relating and applying theoretical concepts to real life problem scenarios in the classroom contexts.

One of the key programmes at ITI is a Postgraduate Training Programme known as the “9-Month Professional Diploma”, where every year around 1,000 graduates embark on 26 different specialisations. All of these students on this programme take a project management strand [30 hours] during which they are introduced to the principles and the concepts of project management and techniques. In the final stages of the programme, the graduates carry out an independent project, but all too often were unable to apply their learning of project management theory and skills to the real context of their projects, and usually they need significant reinforcement to enable them to complete their project and tie what they have learnt before with the projects that they will go through, no matter how good they have done during their 30-hr project management course. This inability of the graduates to apply the theory to practices was highly problematic. Graduates were able to perform well in project management course’s assessments, but were less effective in the application of project management techniques to real problems, and performed less well in their practical project. Graduates in the programme seemed unable to deal with the dynamics of a real project and there was a need to think of a new kind of approach that will help them to bridge this gap in an engaging and effective manner.

Having seen how the middle managers in the EU project, responded to the systems thinking and how it helped them to visualize the dynamic systems through SD simulations and graphs, triggered the idea of exploring if this approach could be of value and impact with less experienced project management students.

Of course, there are major differences between the new graduate project managers and the middle managers, primarily because the latter have much more real world experience whereas the new graduates lack this experience and lack the ability to know in a practical way how a real project can change in unpredictable patterns that can make it more challenging. SD simulations which have the ability to present visually the changing dynamics of complex systems could potentially provide real opportunities for the new graduate project managers to see these changes, observe, and practice.

This study sets out to investigate if SD simulations on complex management topics could give project management students a more realistic view of the dynamics of complex problems and help them to better understand and apply the different PM concepts and practices.

1.7 Contribution

In order to assess the impact of SD applications on teaching a complex management topic, Earned Value Management (EVM), this study will contribute in demonstrating that:

- SD helped in improving Project Management (PM) students' learning skills with a special focus on the areas of knowledge acquisition and analysis, this was shown through a groundwork study that assessed two groups' post assessment. Discussing the quantitative results of the participants' post assessment scores and the qualitative results of the participants' text responses, feedback, and their elaboration on the post assessment questions provide a strong base of assessing the impact of SD teaching-based simulations on the students' learning skills,
- It also demonstrated that SD based teaching approach is more effective than using the traditional methods through a different groundwork study from the existing work in this area. Other researches, are only focusing on assessing the learners' acquisition of system thinking basic concepts and not tackling the impact of SD on understanding the topic itself through a clear methodology of design, and assessment guided by one of the instructional design framework, which is Bloom taxonomy in this case.
- The study provided advice for the educators, SD researchers and the learners through a set of guidelines on the design-associated considerations, mapping these guidelines to the formative design goals of the experiment that will be explained in chapter 5.
- The study contributed to the existing theories and work, through developing a design of accumulative phases. This design is not only considered as a practical ground work, but also contributed in providing practical guideline and evidences that adds up to the existing descriptive theoretical evidences about the impact of SD on education.

- The study also contributed to providing training material, a series of SD models that would be of help to the interested researchers who are looking for further exploration in this area, and assessment methodology that will rely upon clear quantitative and qualitative design.
- The study also contributed with the revision and the discussion about the similar SD work in the area of teaching project management and highlighted the main differences among them and what distinguish this study from other work.
- The study results contributed defending the SD criticism, as the study results showed in practice how its commitment to mathematical relations is not against the relational ontology, and defends its capabilities through practical assessment and analysis to this assessment.
- The study also contributed to the needed programs for preparing well-trained calibers in the field of PM in Egypt.

1.8 Thesis Outline

In order to answer the study's main question: If SD can really improve the learning of a complex topic such as project management , it is important to decide on the best way for investigating such causal relation between the teaching approach using SD from one side and the PM learners' skills from the other side.

The selected approach in this study will be based on conducting a true learning experiment, with a random assignment of subjects on two groups; the control group; which is the group that will undertake the traditional way of teaching and the experimental group, which will undertake the modified approach of teaching using SD.

In order to answer the research questions related to the SD impact on handling the encountered challenges with project management teaching, there are different overlapped subareas that need exploration with more measurable criteria and supporting referenced theories, including for example; what are the complex features of project management that are considered challenging when it comes to teaching? What is the kind of opportunities that could be delivered using modeling and simulation techniques at large? Why specifically SD has been selected for the study, knowing the various criticizing literatures to SD? How to prove its assumed impact? What is the methodology that will be used? How to maximize the validity and the reliability of the proposed research method? What will be the assessment types and how it will be analyzed?

These questions lead to an overarching methodology for the study to include:

- Stating the problem and presenting the research hypothesis and questions
- Designing the experiment that will test the research hypothesis, studying the potential problems associated in the experiment in terms of its validity and reliability
- Designing and developing the control and experimental learning context
- Conducting the experiment, and the collection of both quantitative and qualitative data
- Analyzing and discussing results

This reflects on the structure of the thesis, which is elaborated on through the following section.

1.9 The Structure of the Thesis

The following summarizes the structure of the thesis and chapters' breakdown:

Chapter 2

This chapter reviews in a converging way the evolution of the different project management approaches, project management techniques, the required competencies and skills for project managers, and the challenges encountered in teaching and training of sufficient number of qualified project managers. It then explores the gap between the required skills and the current approaches of preparing these managerial skills in terms of the growing need for qualified project management practitioners, the learning theories and simulation tools that would be facilitating the learning challenges, the spectrum of simulation and modelling. And finally, it will give an overview about SD, and compares it to the other main simulation techniques, its limitations and the research school that is against SD, and reviewing similar work in this field focusing on how different this study is from the other existing ones in the same field.

Chapter 3

The chapter will present the research hypothesis, questions, its underlying rationale, an overview of the entire research strategy, including the adopted experimental methods and the road map of the pilots' implementation. Additionally, it will tackle the research validity with particular emphasis on the experimental approaches used in an educational context.

Chapter 4

This chapter will cover the design of the lesson plan focusing on the Earned Value Management topic, the development approach for the lessons – control and experimental, and the design of the assessment techniques that will be used to test the research hypothesis.

Chapter 5

It reports the key phases of the design and development of the lessons that were followed during the study, how these phases were refined to make sure of the validity of the study's independent variable. This chapter also reviews the different pilot phases and its feedback reflected on the final experiment.

Chapter 6

This chapter presents the results of the main study, providing both a quantitative and qualitative analysis and a discussion of the key results.

Chapter 7

This chapter provides a set of guidelines and feedback for the tutors of project management, researchers and developers of SD modelling approaches.

Chapter 8

Finally, this chapter summarizes the contributions of the research study, outlines lessons learned, opportunities and recommendations for further work, and finally the conclusion with respect to the main study hypothesis and questions.

Chapter 2 Literature Review

2.0 Overview

Projects in different areas such as construction, industrial manufacturing, agriculture & irrigation control & monitoring and software & technology development have evolved. Project management approaches have developed in parallel with this evolvement to deal with the growing complexity of projects in such areas (Shtub, 2012). However, project management still fails to deliver on the key outcomes, leading to massive losses in terms of the failed projects' statistics (Gartner, 2012; PMI, 2014a, 2014b).

Projects fail due to many reasons. On top of these reasons, the managers' ability to comprehend the projects' complexity encountered in the underlying dynamic relations between the projects' indigenous and exogenous controlling variables (Shtub, 2012; ESI, 2013).

The project management curriculum has likewise attempted to deal with the evolving needs of the project management (Wideman, 2002; Wysocki, 2007; Collet, 2013; Dave, 2010). Teaching methods were diversified in an attempt to bridge the gap, through the usage of different delivery methods (Williams, Loucks, 2012). One of the key approaches that attempt to solve this challenging problem is the use of simulation techniques, because simulation techniques can provide authentic contexts of the real complex world in a way that enable managers and learners to try and learn in an experiential way (Quadrat-Ullah, 2010; Altschuller, Moscato, 2012).

There are different simulation techniques; one of them is System Dynamics that is considered one of the significant methods in helping project managers to deal with complex situations that are characterized by dynamic behaviour, and interrelated, feedback relations (Quadrat-Ullah, 2010).

SD has been used in education in a number of contexts, for example; to help the students to understand the concepts of different theories like acceleration, Newton laws, etc. This way helped the learners to grasp the idea of dynamic behaviour and time factor of interrelated variables that wouldn't be easy to hold in a theoretical manner (Forrester, 2009a, 2009b; Schaffernicht, Patricio, 2010).

SD has also been used in project management education, but there has been no systemic, thorough, and comprehensive approach that discussed and assessed the pedagogical approach of using SD in learning and assessing its impact on the students' learning skills in details. To date, there is no study about the use of SD in teaching project management that has taken a rigorous approach to understand the potential benefits of this in helping learners to deal with the complex multivariate work of the projects, the existing experiments are limited to use system dynamics as system thinking tools rather than assessing its impact on understanding the topics itself (Pfahl, et al. 2003; Uzzafer, 2013; Cruz, Eduardo, 2014).

This study sets out to conduct an investigation into the use of SD in the field of teaching project management, and assess the designed learning lesson using the guidelines of Bloom taxonomy. The outcomes of this study will help to understand the impact of using SD on the learning skills, and will provide a set of guidelines for practitioners, learners, and educators.

The chapter will tackle a set of questions, in a converging way, starting with the discussion of the different PM approaches, the current challenges encountered in PM education in terms of the curriculum and the delivery approach, how can simulation help in addressing these challenges, and how SD as one of these simulation techniques can help in addressing these challenges, as illustrated in figure Fig. (1).

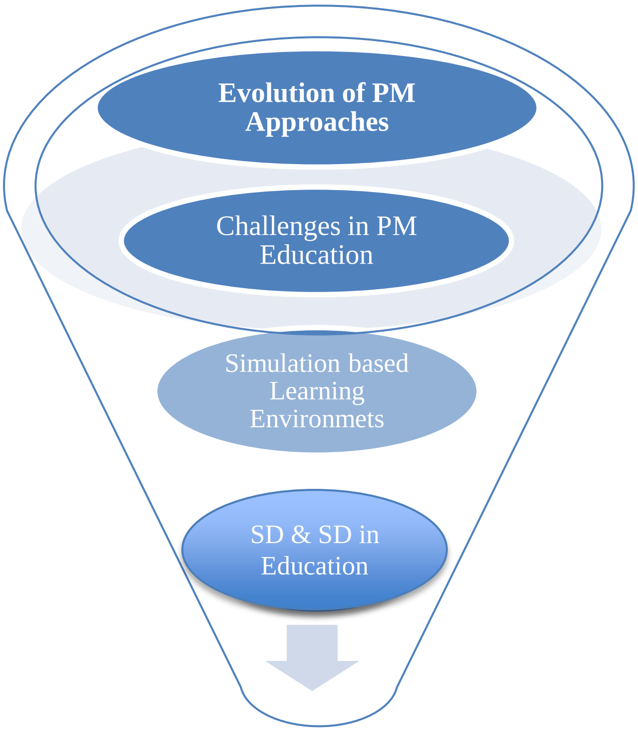


Figure (1): The Literature Review Road Map

2.1 Evolution of Project Management Approaches

2.1.1 Key Project Management Approaches

The first step in Fig. (1) is about the evolution of PM approaches. Different approaches have been evolved and developed to serve the aim of managing projects. David Frank referred to the basic aim of any project as to accomplish a task within the allocated budget and time, while maintaining the quality of the final product (Frank, 2012; Madsen, 2005). To help managers realizing the project's goals, in a standard way, there are different approaches and guidelines that were developed to create a common language of understanding and handling projects. This section reviews the different project management approaches with a focus on how they are handling the growing complexity of the projects differently.

One of the early-developed project management approaches is the Project Management Body of Knowledge (PMBoK) (Levi, 2009; Wysocki, 2007). The Project Management Institute (PMI) published its first version in 1987. PMBoK is a collection of processes and areas of knowledge that are generally accepted as best practices in the field of project management. PMBoK follows the typical problem solving technique, through describing the project in terms of a sequence of steps that includes initiation, planning, design, execution, monitoring and control, and completion. These steps represent the function-based knowledge areas of a project with illustrations of its related processes, the used tools, and techniques (Wideman, 2002). Sometimes management style is a task or a function oriented, this is why PMBoK is suitable for understanding the different functions of project, However; not all projects can have such well-defined phases or stages or functions, many kinds of projects might not follow this structured progression, and may include closed iterative loops around the stages of its implementation that include planning, execution, and monitoring.

Another approach developed by the United Kingdom government agency Office of the Government of Commerce in 1989, is called Projects in Controlled Environments, version 2 or shortly (PRINCE2). PRINCE2 was released in 1996 as a generic project management approach. PRINCE2 divides the project into a set of processes; each process has its input and outputs, tied with each process its key inputs and outputs with specific goals and activities to be carried out to deliver the project's outcomes. PRINCE2 approach tackles the project from its processes prospective rather than from its functional areas as being done by the PMBoK approach. This makes PRINCE2 easier in implementation and PMBoK easier in learning (Collet, 2013).

PMBoK and PRINECE2 are better to be seen complementary to each other, as PMBoK is more into a reference guide that focuses on the project’s knowledge areas, whereas; PRINCE2 is on the other hand, considered as a manual that looks at the project from the process point of view,

- A relatively recent approach is "Agile Project Management" which is considered as a spinoff from ‘agile software development’ in 2001. This approach focuses on individuals and interactions, appreciate the customer collaboration over the sharp edge of contract negotiation. In short, the Agile approach appreciates the continuous customers’ engagement and their dynamic changes over restrict sharp requirements in the beginning of the project planning. Agile can deal with the change effectively, however; its success depends on having the availability of the client all the time to be engaged in the different project phases (APMG-International, 2011) so it fits more with small and adaptable projects,

In Summary, the main points are:

- Both PMBoK and PRINCE2 are popular and well referenced with different geographic dominance, PMBoK is used more in US and has a vast impact in upgrading managerial skills yet; it presumes that projects have well defined functions which is not always the case.
- On the other hand, PRINCE2 is well recognized in Britain and it is characterized as logical and linear approach, which is not sufficient, because PRINCE2 assumes an idealistic project structures, processes and life cycle based framework, which is beneficial at the beginning to understand the projects in a simple way. However it is not sufficient to grasp the practical view of projects, knowing the complexity and difficulty encountered in most of real projects (Cockburn, 2008; Collet, 2013).

Despite the increasing number of these approaches, that offer different lenses in tackling and managing the projects, yet projects still fail. This challenge is quantified through the annual projects' performance statistics. The analysis of these statistics is highlighting on the different reasons behind the projects' failure. The following section will discuss these statistics, and the main reasons behind the failure of most of these projects.

2.1.2 Project Management Failure

Every failed project has its own set of issues, yet there are common reasons behind the failure of the projects. Understanding these reasons, will help providing guidelines for further development.

McKinsey developed a report in conjunction with Oxford University in 2012, surveying around 5200 IT projects indicated that about 45% of projects run over budget, and another 56% were delivered with less value than predicted (Bloch, et al., 2012). Another survey was conducted in 2007, developed by Dynamic Markets through surveying 800 IT managers, where they found that around 62% of the projects have overrun on time, and around 49% of projects encountered over budget problems (Dynamic Market, 2007). The problem of time delays has been highlighted in another survey that was conducted by Gartner, indicating that around 50% of the failed projects are due to the substantial delays and the improper time management of projects (Gartner, 2012).

In light of this significant number of failed projects, what are the reasons behind this failure? Highlighting these reasons will help in moving towards the needed actions for better preparation, which will be tackled in the following section.

2.1.3 Why Projects Fail?

The importance of the previously highlighted statistics is in its direct relation with the list of the recommended essentials of these surveys that should be considered. Talent management was one of the main essentials. Talent management factor drives attention to the training and development process in this field. Project Management Institute highlighted in their report dated in 2013, the crucial role of the developmental processes of human resources in the field of PM (PMI, 2014a). It is worth mentioning that PMI is the world's largest non for profit institute membership association for project management profession that was founded back in 1969, serving around 2.9 million professionals around the world and founded its chapter in UK back in 1996.

Also, in their study about the failed projects, IBM has published their findings in 2008 about the top five reasons behind projects' failure, through which they have attributed the majority of the failed projects to a list of barriers that are related to the proper talent and skills (IBM, 2008).

In other different reports, it was clearly shown that there are inadequate trained project managers regardless of the increasingly existing number of project management approaches and their existing training programs (Standish Group, 1994; Frank, 2003; Marando, 2012). They referred to this challenge as a common one, with most of the projects that encounter different affecting variables and supposed to be developed and fulfilled within specific time and budget.

In the report of AT Kearney, there was a special focus on the scarce resources of fresh and expert levels of project managers in Egypt, through which they have proposed a set of programs, training, and degrees to fill in this gap (AT Kearney, 2007).

In their annual global survey with project management professionals and practitioners, PMI discussed the different critical factors that determine the success of projects. They found that the skill set of the program or project managers was one of the main concerns (PMI, 2012), and equipping the team with the appropriate and required skill set is always on top of the required list for successful project management (PMI, 2012).

Having, the talent qualification as one of the reasons behind the failed projects raises another question about the type of skills that should be considered in the projects' training development and to zoom in for more specifications about the characteristics of a good project management talent.

Of course the spectrum of the required competencies is not limited to one type of the skills that could be handled through one proposed approach. Skills and competencies vary from soft, to behavioural, cognitive, and technical skills (Maciver, 2011; Morris, 2007; Brill, et al., 2006). However; the scope of the current study is about the usage of SD as one of the simulation tools in handling the challenges related to skills of understanding a complex topic like project management, and how to improve the delivery of such dynamic interacting featured topic. So it is important to further converge towards the exact kind of skills and competencies that are required.

In their papers, (Mengel, Thomas, 2004) and (Crawford, 2005) highlighted the lack of training and practices that are related to the complexity and the uncertainty (Mengel, Thomas, 2004; Mengel, Thomas, 2008) and Cicmil further emphasized the need for set of skills that would enable the learners to act with confidence within dynamic and complex organizations (Cicmil, 2006). How to develop these skills, this is what will be discussed later, but first, and before discussing the 'How', let's see the currently used methods to develop these skills, through addressing the existing curriculum and its delivery.

2.2 Challenges in Project Management Education

This section will discuss the project management education in terms of the existing curriculum and teaching delivery methods, and will discuss the challenges of the existing methods in handling a complex topic such as PM, and how can other delivery mechanisms like simulation can contribute to handling these challenges.

2.2.1 The Project Management Curriculum

Back to figure Fig. (1), this section will discuss the existing PM education curriculum and teaching delivery and its challenges as previously mentioned, in section 2.1.1, there are different project management approaches, which consequently entail having different types of teaching materials to suit each of these approaches. For each of these materials, there are some common features that are seen important and as a must from the pedagogical point, yet from the practical point of view; these features raise a challenge in their way of handling a complex topic such as project management. For example, the curriculum is relying on delivering theoretical exercises or a set of questions for examinations (Williams, Loucks, 2012), particularly at the post graduate level. Tatnall and Reyes have found that graduates; often lack a practical frame of reference. Hence; if the material is presented only in a theoretical manner, some of the nuances of project management issues are eventually missed (Tatnall, Reyes, 2005).

Another feature is related to the way of structuring the curriculum, through breaking it down into different components, and accordingly having separate components that are targeting specific set of competencies for each different component in the project, with clear absence to the interrelations between these components, as each separate part or component is being analyzed in details and facts are established and reassembled later on, in a theoretical way (ICCPM, 2012). Again, this breaking down approach is good as a teaching reference for introducing the basic definitions and knowledge of the topic. But the sole reliance on this simple view, contributes to creating a challenge in real life scenarios where learners found themselves dealing with a combination of various interrelated variables that have been previously taught separately, explained in separate chapters. For example, one cannot change the project schedule without affecting the project cost. Besides, it is impossible to directly control time or cost which is the most indicative project's success factors without including the effect of engaging resources (Liberzon, 2006).

As discussed in section 2.1.1, PMBoK and PRINCE2 are looking at the project from different points of view. For example; in tackling project's resources in terms of roles and responsibilities, PMBoK is concerned with defining the roles and the responsibilities, whereas PRINCE2 provides a model on how to set up the team and the standard role description. Each has its own focus, one on the knowledge areas as with PMBoK and the other with the processes themselves as with PRINCE2. However; the previously discussed common features in terms of lacking practicality and introducing the topic in simplified isolated sub-topics are still challenges with both, no matter how differently they are tackling projects.

Structuring the curriculum is useful and suiting the learning and knowledge transfer process from the pedagogical view, yet there is a need to complement it with another technique that will enforce the nature of the realities and made it more closely to life profession dynamics. This is explained by Shepherd when he calls for: the need to emulating the real profession into the educational approach to be more practice oriented (Shepherd, 2004). Sometimes this feature is considered as an option, and in other cases it is a must. This depends on the nature of the taught topic, such as with the case with project management courses (Tatnall, Reyes, 2005).

Addressing the project management real world problems, cannot be tackled through the existing sequential structured approach only, cause it is significantly limited by its failure to address the interaction, interdependence between the constituent parts, which is a core nature of projects in general (ICCPM, 2012).

This study does not aim at proposing restructuring the content framework. However, it reviews and discusses the limitations with the existing curriculum, analyses how it adds up to the overall challenge of teaching project management, and trying to explore the possible ways that will enforce this practicality.

To reach this target, it is important to start with reviewing the existing delivery techniques, so that what is being missed within the curriculum might be taken care within the delivery methods. This will come in the next section.

2.2.2 Teaching Methods in Project Management Education

In 2011, a study was made at the University of Kuala Lumpur, trying to identify the most effective teaching delivery method. The study showed an appreciation to the traditional lecture format in developing the participants' knowledge in specific field. Also, they pinpointed another problem that is related to the difficulties faced by the learners when trying to understand the theory and the practices through the traditional lecture. The study recommended further engagement techniques through exposing the learners to real experiential learning environment (Ibrahim, 2011).

Lecturing is probably the oldest instructional format, today it is still the most common form of instruction (Hrepic, et al., 2007). The most highlighted limitation to this teaching delivery model is its limited ability to include the real-world learning experiences (Duffy, Cunningham, 1996). The impact of this limitation affects the learners in different ways, and this will depend on the nature of the taught topic. In the case of project management field, where practicing is a critical factor to grasp the theories, this impact is huge.

As stated by Henning, the conveyed Knowledge in the classroom tends to be situated in the context of the classroom and the school rather than the context in which the knowledge was created (Eichberg, 1998). He highlighted the negative impact on the learner's motivation from separating between the theory and the reality.

The same findings were discussed by Mengel and Thomas in their reviews to the existing models of PM training (Mengel, Thomas, 2008), where they came up with a number of conclusions that include; (i) the focus of the project management training methods on transferring the ''know how" of the knowledge areas, rather than developing the problem solving skills should be revisited, (ii) These 'know how' skills require from the project managers a higher level of competencies that

are related to the learning levels of application and analysis, in order to be successful to apply in reality rather than simply recall information.
Other references recommended collaborative interactive classrooms, and adding more interactive delivery models in addition to the traditional lectures for better learning and skills' abilities, especially with the topics that need practices (Atkins, 2010; Ali, 2011; Williams, Loucks, 2012).

Finally, the recommendations of most of these reviews, are appreciating the role of the traditional lecture model. At the same time, they are calling for further empowerment to the existing model, in a way that would relate between the knowledge theories and its practices. How could this happen; this will come in the following section.

2.2.3 Bridging the Gap between Theory and Practice

The projects' nature of dealing with continuously changing inputs of resources, budgets, requirements, and duration, etc., makes it difficult to use the analytical tools to understand this complexity. This is coming from the dominance of the non-linearity behaviour that will not be totally fulfilled by only decomposing the system into small parts (Sonnessa, 2005).

Modelling and simulation techniques are proposed to be more efficient modalities for learning, to allow for better understanding of PM, when there is no adequate analytical approach, (Alessi, Trollip, 2001). Modelling and simulations will help visualising the whole structure behaviour, and enable the learners to manipulate the system's behaviour through changing some of the affecting variables, hence; getting a complete view to the whole structure with its behaviour (Edmonds, 2005).

Using simulation in empowering the teaching delivery models, enable the learners to observe the theory's behaviour, and freely decide on changing some of the variables and observe its reflections on the overall new behaviour. This will happen in a way that will reflect and reinforce the learners' way of understanding to the different "what-if" scenarios of the behaviour (Bakken, 1993; Lainema, Nurmi, 2006; Quadrat-Ullah, 2010). Again, simulation can add up to the lecture-based delivery technique, to offer the most suitable method for educators to help teaching both project management concepts and practical skills (Geist, Myers, 2007).

In summary, there is a need to bridge the gap between the knowledge and the skills; between the classroom and the real world experiences, this is coming from the nature of the projects that are open, emergent and adaptive dynamic systems characterized by causal and non-linear feedback loops. The question now is, how to enrich the conventional teaching methods using simulation techniques, how to realize on the ground a valid model, based on which type of simulation models, and why. These questions will be addressed in the following sections.

2.3 Simulation-based Learning Environments

2.3.1 Simulation and Learning

Now, we have reached the third step in Fig. (1). Simulation can provide interactive learning environments to enable and enforce the experiential learning (Quadrat-Ullah, 2010), that means, it supports the learner with the opportunities to be the main actor who can observe, take a decision and instantly access to the overall system feedback. This active role will enable the learners to get more engaged through interacting with a complete virtual world (Altschuller, Moscato, 2012). This level of freedom allows the learners to observe, change, evaluate and assess then reflect on their performance in another environment that almost mimic the real world, through providing virtual experiential learning space.

Simulation impact on the learning process is related to the definition of the learning process. Learning is defined as the process where knowledge is constructed by the transformation of the experience (Adobor, 2006; Wall, Ahmed, 2008). So simulation can provide this safe environment to construct the knowledge as well as transform and practice it.

Although, the positive impact of simulation has raised another concern, related to the simulation's unlimited free learning opportunities, and whether this unlimited freedom will really improve the learning skills or confuse the learners. Yet; the current study looks at this concern from a balancing perspective, in a way that considers simulation as a complementary way to the other instructing teaching forms; through giving the learners the opportunity to experiment and get engaged positively rather than being merely receptive (Min, 2000). This complementary role is coming from getting engaged with the technology in a way that gives more opportunities for better engagement of the simulation in the training and educational process and with less risk if properly designed. These design issues is another aspect that is related to the implementation and will guide for better usage of the simulation and control the raised concerns around it. These design considerations will be addressed in more details in chapter 4 and further discussion about the concerns around the simulation will come in the following section.

2.3.2 Simulation in Project Management Education

Traditional project management teaching methods relies mostly on textbooks, articles and case studies, which give good, array of knowledge and practices however; they are static in their nature as they are giving a base of theoretical information and knowledge. Simulation can complement and add value on the practical levels, where change in project management is vital to the success of the different projects (Shtub, 2012).

Simulation is being recommended through a way that provides a context for the learners in order to teach them the concepts of the wholes. The context should place students in a situation that is similar to the one in which they are going to apply the knowledge (Simulation and Learning Theories, 2013).

Actually these recommendations are coming from the simulation's ability of letting the learners 'do' rather than merely 'listen', emphasizing questioning, offering opportunities of examining scenarios that underlie the system behaviour, creating a discovery learning environment, facilitating the understanding between relations and its underlying feedback, and increasing retention, when properly guided by the trainers (Grieshop, 1987, Shtub, 2012).

However; on the other side, there are researchers who doubt the impact of computer simulation on the creativity and the learners' abilities to originate new useful ideas (Betz, 1996; Gokhale, 1996; Harkow, 1996). These concerns are being driven from different conditions such as the type of the offered learning that gives the learners more freedom to explore and try various planned or unplanned scenarios without appropriate coaching scaffolding (Duffy, Cunningham, 1996), feedback and debriefing, cause learners might deal with it as a mere game (Leemkuil, et al., 2003), and eventually the learner gains little from the discovery learning simulations (Min, 2001; Heinich, et al., 1999).

Also some constructivists argue that the educational simulations are oversimplifying the complexities of real-life situations, which led to giving vague and not accurate understanding of a real life problem or system (Heinich, et al., 1999). This is another form of “video arcade syndrome”, which is a common criticism about the users who are falling into this effect; the same way they can win the game without having any clue about how it happened (GröBler, et al., 2000). Addressing these concerns, is always through controlling the design and allowing for proper human facilitation support and mentorship; this will handle these types of concerns and help in assimilating the new knowledge with the existing mental models (Quadrat-Ullah, 2010).

Other concerns are related to the fidelity and the validity of the simulations. The fidelity of the simulation is the measure of its deviation from the real situation it is considered as one of the critical factors that are influencing the transfer of learning (Alessi, 1988). Other concerns are related to the simulation validity, as forgetting the validity conditions of the models might lead to misleading results (Fritzson, 2003). To conclude: simulation can provide different supportive and facilitating tools in terms of communication, visualization and interaction, and also can lead to fault and fuzzy results, if there is no proper planning or designing for the work on the ground. To stand on the exact impact of this mix of features, and to discuss each party’s arguments, there is a need for further empirical studies to support either view. Especially in light of the limited available assessed simulation work based on grounded evidences rather than being offered in a descriptive way (Issenberg, et al, 2005; Landriscina, 2013)

This study is needed to fill in this existing gap, and to contribute in building a strong base of evidence that demonstrates its effectiveness. This is why the next sections will converge into the kind of simulation technique that can be used, and how practically it could be implemented for further assessment.

2.3.3 Key Simulation Approaches

Computer simulation has been used successfully in many practical fields including engineering, management, medicine, technology, and others. As introduced in the report of simulation-based engineering and science by Glotzer: "No field of science or engineering exists today that has not been advanced by, and in some cases utterly transformed by, computer simulation." (Glotzer, 2009). In his critical review about modeling and simulation, Oren listed around four hundred types of modeling and simulation (Ören, 2011), through which he referred to different lenses one can use and choose to perceive modeling and simulation, these different lenses include: (1) Purpose of use, (2) Problem to be solved, (3) Connectivity of operations, (4) Types of knowledge processing, and (5) Philosophy of science (Ören, 2011). The simulation types could be categorized based on its own applications and unique usages in main categories (Mchaney, 2009) to include:

- Discrete Event Simulation (DES)
- Agent Based Simulation (ABS)
- Continuous Simulation including SD. In some cases, Games is being identified as a separate type, and in other cases, it is seen as a part of one or more of these main categories when being discussed, based on its underlying structure.

The following will highlight the main usages of each of these categories, followed by a special focus on the selection of SD for the purpose of the study.

2.3.3.1 Discrete Event Simulation (DES)

DES is one of the simulation types that models mathematically and logically the operations of the system as discrete sequences of events in time. The behaviour of the system here changes by the events and at precise point of times (Albrecht, 2010), this kind of simulation is being characterized by the passage of blocks of time during which nothing happens, punctuated by events which changes the state of the system (Mchaney, 2009).

Example for different DES areas of applications might be seen with customers queuing systems, and inventory management of its parts.

2.3.3.2 Monte Carlo Simulation

The name has been given to reflect its gambling similarity, where repetitive trials are dominated with no importance to the time representation factor. The name has been initially used by John Von Neumann as a code name for his initial development of atomic bomb that was conducted based on the use of random numbers.

The name is used to represent simulations that are into a scheme employing random numbers, which is used for solving certain stochastic or deterministic problems where the passage of time plays no role (Law, Kelton, 2000; Mchaney, 2009).

2.3.3.3 Agent Based Simulation (ABS)

Sometimes, ABS is called individual based models, it simulates the simultaneous operations and interactions of multiple agents, in an attempt to re-create and predict the appearance of complex phenomena (Helbing, 2011).

The concept of ABS is that an overall behaviour of the system emerges through the micro level interactions of individual agents; based on an assumption of generating overall complex high level behaviour founded on simple local behaviour (Mchaney, 2009).

2.3.3.4 Continuous Simulation including System Dynamics

This type of models is concerned with representing the system behaviour over time and models mathematically and logically the operations with continuous changes over time. Continuous simulation are commonly developed using spreadsheets, specialized software as MATLAB or Mathematica (Mchaney, 2009). System dynamics is one of the types that are used to describe the continuous dynamics of the systems; it describes the system behaviour, showing its interrelated, interacted feedback loops, and the underlying delays that affect the whole system behaviour (Forrester, 2009a).

2.3.4 Simulation Approaches: When to Use What?

There are different criteria in choosing the most appropriate simulation package for the relevant application or problem area. These criteria differ from person to person or firm to firm. Criteria are determined by consulting the experts and program dealers (Nikoukaran, 1999; Hlupic, 2000). Some questions can help deciding on which simulation type can be used, for example like; what questions does the model user wish to address, and for what purpose will the model be used. So sometimes, the nature of the problem determines the simulation approach and in other cases when it doesn't matter the underlying used simulation technique itself, the willingness of the modeler plays role in this choice depending on his previous experience.

SD for example is best suited for the problems associated with the continuous processes, where feedback significantly affects the behaviour of a system (Sterman, 2000). DES models, in contrast, are better at providing a detailed analysis of systems that are involving linear processes and discrete changes in the system behaviour (Banks, et al., 2000; Matloff, 2008).

ABS is being used to explore the detailed behaviour of autonomous, responsive and interactive agents that will interact with each other in order to achieve their objectives; this is a bottom-up approach (Samuelson, Charles, 2006).

There is certainly a large area of overlap between the two approaches of DES and SD. Many problems could be modeled with both approaches, and produce results that would look very similar. Both methods, when used appropriately, can help provide increased understanding of the situation and serve as an aid to the decision-making process. Sometimes, there are recommendations for applying different approaches simultaneously to ensure that we do not become trapped either by the deterministic fantasy or the unnecessary mathematical details.

A comparative study between the different simulation techniques is illustrated in Appendix 1. Now, the following section will highlight the choice of SD among these simulation types.

2.4 System Dynamics

2.4.1 Origins of System Dynamics Approach

SD is popular for its ability to observe the dynamic behaviour of linear and non-linear system, viewing the cause and effect between different interrelated variables, and exploring the impact of delays and trade-offs on the whole performance of the system (Sterman, 2000). SD is being used to improve the understanding of the interdependencies existing between the system structure and its behaviour, and the extent to which various policies influence its functioning mechanisms (CEPAL, 2014).

In the mid 1950's, Jay W. Forrester was working with some of General Electric managers on business cycle of employment using calculations. Forrester through these calculations was able to show how the instability in the firm's employment was due to the internal structure of the firm and not due to an external force such as the business cycle. These manual simulations represented the emergence of SD. After this, and during the period from 1950-1960, Forrester and his team moved SD from the mere calculations phase to the formal computer modeling phase (Forrester, 1989; Forrester, 1990; Richardson, 2011). Since that time, and after developing a convenient Graphic User Interface for SD software that made it more user friendly, this led to wide diffusion to the usage of the SD applications in various areas.

If system thinking is a broad concept of looking at things in a holistic way, revealing patterns of behaviour and seeing the underlying relationships, then SD is defined as the practical tool for building, visualizing and practicing system thinking skills that reveal dynamic and feedback relations (Richmon, 1994; Caulfield, Maj, 2001).

It's worth noting, that beyond these formal dates of systems thinking official start in references and books, evidences for several systems thinking approaches and concepts could be found, even if there was no mention of the exact words of ‘system thinking’, and no clues to its formal theoretical existence at that time. For example, observing the mega project of building the Pyramids constructed by the ancient Egyptians will show a project that was built based on the application of interdisciplinary sciences of engineering, astronomy, mathematics, geometry, chemistry, and architecture. This level of systemic view in dealing with various interacted sciences, can be seen in the building’s construction that exactly points the pyramid's base to the four main directions, building the pyramid shaft to point at Orion, the upper line which runs between north south passing by the tip of the pyramid, divided the Nile Delta into two equal parts. The geometric construction represented in the exact triangle, squared base, and pyramid shape and the chemistry behind preserving the colours of drawings. Constructing the great pyramid seems to be one of the world’s largest and most comprehensive system based ventures. At these times, people may have not used the word ‘system’, but no matter what synonyms of the word system used are, the underlying implemented theories all indicate the presence of an advanced level of understanding and the ability to see a system of interrelated topics.

Moving from history to scientific and academic view; thinking in systems in the form of a defined science and approach, has been stemmed from two roots; Cybernetics, and General Systems Theory. In the 1920’s, a research into living things, encountered limitations to the concept of the dominant approach at that time of reductionism, when the Australian biologist Ludwig Von Bertalanffy demonstrated the limitations of reductionism in understanding the existence of organism solely in terms of the behaviour of some fundamental parts, then developed the theory of ‘Open Systems’ that employs functional and relational criteria to study the whole and not only the elements, then he generalized the theory to other fields and called it ‘General Systems Theory’ (Bertalanffy, 1969).

Around the same time, and in parallel to the work of Bertalanffy, Cybernetics came to study communications and control in living organisms, machines and organisations. Together, Cybernetics and Open System Theory became to be called as Applied Systems Thinking Methodology. This methodology begins with the problem identification and concludes with some final solutions, with an expectation that things will attain a desirable condition (Flood, 2007). Reviewing these various systems’ fields like Cybernetics, Open Systems Theory and others from the traditions systems thinking have been summarized by (Reynolds, Holwell, 2010) in Appendix 2, showing some common highlighted features that reflected on what we regard as complex systems and how we view them. Such view, implies changing our perspective of the world's complexity and problems from structured and ideal, stable, constant, and isolated surrounding variables toward linear, dynamic, interrelated, and causal surroundings.

System dynamics is designed to explore problematic behaviour patterns that are caused primarily by the feedback structure of the settings (Barlas, 2007). This is why, and in light of this statement, the objective of this study is to analyse the impact of SD as the selected simulation and modelling tool on facilitating and improving the learning process of the complex topics that are characterized as dynamic and complex feedback systems, such as project management.

2.4.2 Overview of SD Key Characteristics and Components

Complex and dynamic situations differ from the situations with static decisions in three aspects: first; a number of decisions are required rather than one decision, second; these decisions are interdependent; and third; the whole system or environment behaviour changes as a result of all or part of these decisions (Edwards, 1962, Quadrat-Ullah, 2010). System dynamics is considered as a "means of inquiring into the behaviour of part of the world in order to understand it and hence indicate ways of improving its performance" (Keys, 1990). Researchers mapped the former complex dynamic aspects to SD features and components that include: feedback, time delays, and non-linearity (Moxnes, 2004, Sterman 1989a; Quadrat-Ullah, 2010), hence; nominate SD as a potential simulation tool to deal with this kind of complexity.

Taking for example one of the PM cases and discuss its challenges through applying SD will show the credential of nominating SD to tackle PM challenges; for example in PM, learners used to deal with projects' case studies, that are supposed to be planned and scheduled within a specific period of time, allocated resources, and an estimate of budget, and all of this is planned to target the project's scope. These different variables are interacting once the project started. Considering the changes that might come from the customers, funding scheme changes, attrition rate of staff, and communication implication on the target progress, is a part of the project nature. During the project, sometimes adding new staff can help, and in other times, adding new staff at different point of time can negatively affect the progress. At any selected point of time, project manager is assumed to be able to plan, monitor, judge, react, estimate, and see his actions' consequences in a casual effect manner. It is not an easy skill to appreciate all of these dynamic interactions, delays, feedback structure in a linear and nonlinear way, without being able to understand and experience all of this complexity. So how SD can help visualizing, experiencing, and practicing these different scenarios. This needs highlighting the main components and the working model of SD

SD models include a group of components that constitute the system structure; this structure is the base that will drive the system's behaviour. The structure consists of feedback loops, stocks and flows, time delays that are derived from the accumulation processes, and non-linearities that come from the interaction of the basic structure's components (Sterman, 1989b).

The problems or situations are represented through what is called a causal loop diagrams. It is a simple map of the system representing its components and their governing relations. There are two feedback loops; one is called the positive reinforcing loop, as shown below in Fig (2). The loop is related to the growth rate and its relation with respect to the decline rate, as represented below. There are two feedback loops, the positive reinforcement loop on the left, indicates that the more growing rate, the more affecting in the capacity limitation of the system, this link is positive, which is denoted with a "+" sign. The second feedback loop on the right is negative reinforcement (or "balancing"). Both loops are simultaneously working together with different or similar rates, which will eventually affect the system capacity limit. A causal loop diagram in system dynamics (CLD) is a causal diagram that aids in visualizing how different variables in a system are interrelated.

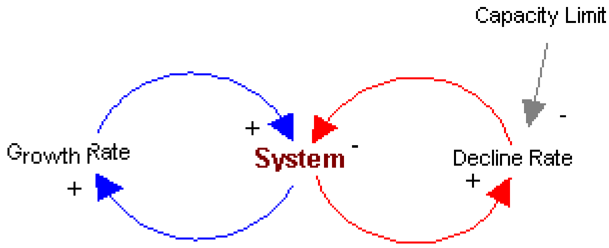


Figure (2): SD Positive Reinforcing Loop

A map of causal influences and feedback loops is not enough to determine the dynamic behaviour of a system. Performing a more quantitative analysis, Fig (2) of the SD positive reinforcing loop or the causal loop diagram is being transformed to stock and flow diagram as in below through Fig (3). This diagram represents a simple SD stock and flow. A constant inflow yields a linearly rising stock; a linearly rising inflow yields a stock rising along a parabolic path, and so on. Stocks components - accumulations, state variables - are the memory of a dynamic system and are the sources of its disequilibrium and dynamic behaviour.

SD computer software transfers the relation of this diagram to a quantitative relation. As being interpreted below, the stock is the term for any entity that accumulates or depletes over time. A flow is the rate of change in a stock. The rate of change in hiring the employees refers to the dynamic change of the number of employees as per this rate of change (Sterman, 2001).

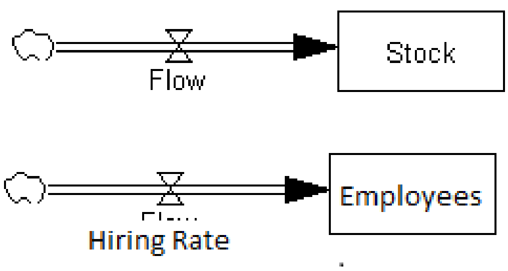


Figure (3): SD Stock and Flow

SD gives the option to show this behaviour over time in a graphical form, for example, Fig (4) visualizes the change in the number of employees in a company or in the bank balance over time as per the changes per their rates as being presented in Fig (4) that will show dynamically the change over time.

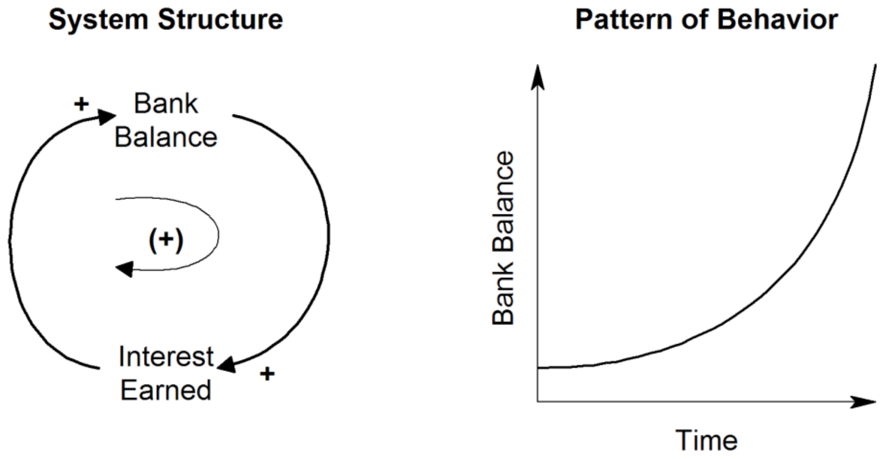


Figure (4): Behaviour over the Time

This is not a spreadsheet. Causal dynamic relations with feedback that change over time in Fig (3) and Fig (4) is difficult to be displayed or visualized through a static graph, and it will be even more difficult with adding extra affecting variables in addition to this simple relation.

The availability of computer modeling tools provides the opportunity to test “what-if” scenarios and to examine the changes in the system behaviour: which is a key characteristic feature of SD. As being illustrated in the below Fig (5) showing different project duration and cost for different staff number allocated for the project. SD allows the learner to change some variables and visualize the effect of changing this variable on the behaviour of the system, as being seen through these different slopes and runs, where each different color slope shows different cost and duration behaviours, each time we are changing the number of the involved developers involved in the project .

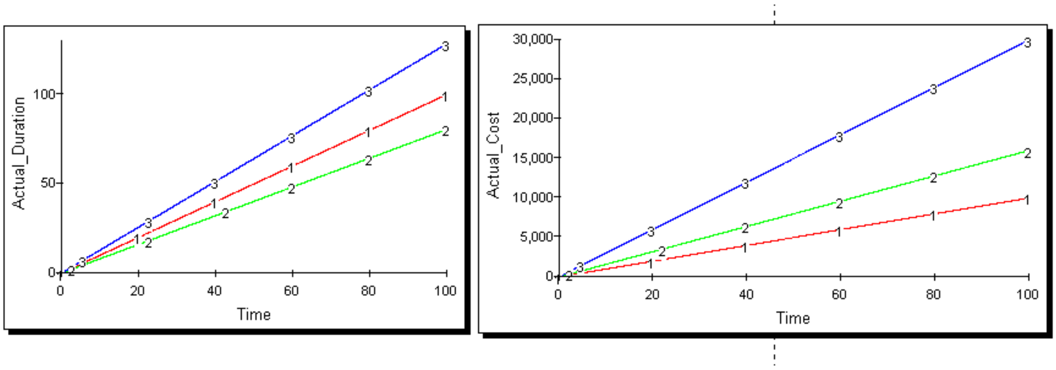


Figure (5): Different Project Scenarios for Different Assigned Staff No. (What-If Scenarios)

Before going into more details about SD applications and its footprints in education and PM, it’s worth mentioning to also highlight the criticism of SD. The importance of this discussion comes from its relation to the validity of SD that if left without discussion might threat the initial potentials of SD that was behind its selection from the beginning for this study.

2.4.3 Criticism of System Dynamics

SD is being criticized for its determinism and its contradiction with the relational ontology (Ansoff, Slevin, 1968; Jackson, 1991). The partial adherence of SD to the hard system methodologies, and its mathematical way of modeling the systems to predict its behaviour, is a kind of determinism that cannot get aligned with the system complexity that it attempts to deal with. It is argued that, the dependence of SD on the quantitative data and the explicit relationships is a sort of commitments to the forms of relationships that hold between variables, these commitments are not coping with the relational ontology concepts in its arguments with the essentialists, and does not allow system dynamics to deal with the complexity of the real world and reduces the richness of the analysis it can conduct (Keys, 1990).

So for example, to deal with the complexity of 'soft' systems, there is a big reliance on the qualitative information and the linguistic terms to describe the complexity (Checkland, 1978; Keys, 1990). It is argued here that this level of details cannot be caught by the hard data and the mathematical models that are used in system dynamics. To discuss this issue, let’s start with an overview about essentialists and relational ontologies.

Essentialists are focusing on the supposed immanent properties (which are atemporal, aspatial, universal) of objects, for example: The rose is a rose and is red, the chair is strong. The criticism here is coming from this specific commitment to the object properties without observing it into context. So, how can we know that this is a strong chair (essentialist) without referring to whether it is strong enough or not for specific purpose (relational)? So: The colour is a relation between light and the object, the weight is a relation between the object mass and gravity, In HCI the demonstration of relational ontologies in use could be monitored in replacing the technological determinism of simple guidelines and patterns approaches by detailed evidence of how actual patterns, qualities and outcomes of interaction arise out of the relationships between the interactive features, socially situated users, and the broader usage context.

Following the relational ontologies that steered the twentieth century thoughts, further arguments have been listed towards poststructuralism and postmodern deconstruction. While structuralist thinking asserted that relations between objects were the key to understanding existence, poststructuralist thinking asserted that there were no stable objects and hence no stable structures. The point here is about the need to balance between parts and their structure and to examine the parts in cooperating with their whole governing structure.

But the question is still valid, how to defend SD in light of this discussion: The criticism is about SD’s specific form of attachment to the mathematical representation between the variables. SD is “The art of linking structure to performance, and performance to structure often for purposes of changing structure (relationships) so as to improve performance”. Causal loop diagram allows qualitative modelling, the stock and flow diagram gives key hint about the structure of quantitative simulation model. Giving a top-down approach to see the dynamics between the interrelated parts with relevant to specific variable is more into relational. So the usage of the qualitative representation by the causal loop diagram is a move towards the modelling of soft systems (Keys, 1990). Although it is argued that the reliance here is still on a single model, yet; this counterargument went some of the way to answering the criticism.

For this quantitative representation’s concerns, it is argued that, the underlying structure is being presented in a qualitative perspective rather than quantitative one (in social sciences) and in a quantitative rather than qualitative one (in natural sciences), but when it comes to quantitative presentation, it is all done in light of the already existing governing theories. It is true, that the model has some constants, but these constants are reflecting the documented assumptions in the theory behind the model, to provide the model basis. For example modelling of the Newtonian law enables the student to see the whole dynamics between the underlying variable not in an absolute manner but versus time, according to the real world laws and its boundaries. So the attachment here to the quantitative relations is about adhering to the governing rules and the theories, and cannot be seen as constrains or forms of commitments. This process of following the governing theory or rule, when it comes to modelling the system, is the same element that would secure the model from design or conceptual validity concerns, which will be explained in details in the next chapters.

To discuss the other criticising point, that is related to accusing SD to be reductionist (Keys, 1990); that is related to the nature of SD to break down the systems into nodes and describing the system through only discussing the interactions of its parts. This is generally seen inappropriate for complex social situations (Ackoff, 1974). The concern here is related to missing the whole objective of the system when drilling into the detailed parts, this is why it is of relevance to refer to Anderson’s point in this regard, as he points out, “to do this, one must have an understanding of the functionality, structure and goals of the 'higher hierarchical' system” (Anderson, 1972). This is what is being done by SD, as it uses complex basic principles to describe complex systems, and doing this, requires an understanding of the structure of the system in question, precisely where the paradigm proposes to start.

The summary is, many of system dynamics criticisms need more practical work and studies in different fields that defend it in a practical way, in addition to the need to more communication with the interested technical and public (Forrester, 2007; Barlas, 2007). This study contributes in putting SD in practice and defends its capabilities through practical assessment of SD impact on the ground.

2.4.4 Applications of System Dynamics in Real World Contexts

SD models provide modelling of dynamical systems that is being deployed in a wide variety of applications, for its general and user friendly approach, and irrespective of the field of application (Roberts, et al., 1994; Fuchs, 2002).

Systems that encounter timed based variables, SD can handle analysing and understanding these systems. This is why, SD as a decision tool could be found in medicine, law, urban studies, governmental public policies, economics, history, finance, chemistry, management and others.

All of these domains can include problems or situations with behaviour that encounter change over time and need to be monitored, analysed, and predicted. This level of complexity can exist in different areas and business fields, for example in the area of policy making, where is usually characterized by natural complexity in terms of the number of actors involved, the many relations and influences, and the ever-growing number of individuals' interference. SD applications in this area are numerous, for example; the SD assessment model to assess and evaluate MALI external military intervention to strengthen MALI military control, other SD applications in the same area could be seen with the models used for the military workforce planning in the Italian Military sector, and others (Onori, 2013).

SD models for Decision making widely exist in Health sector, as the conventional analytical tools are generally unable to satisfactorily address situations with continuous change over time, risk factors, and different resource interventions (Schorr, 1997).

Other examples for SD applications could be found in the field of science and engineering, including chemical engineering and biochemistry. Various models have been made to support the product development, as in this area; there are important factors that determine the quality of a product and a team's ability to meet schedules (Repenning, Sterman, 1997).

Also, applications are there to support the business area of supply chain, in most of the firms, there is a problem related to the volatility of a business' supply chain. As they are either consistently short of inventory, or they have an overabundance sitting in warehouse, using SD the problem is much more readily solvable as its dynamic behaviour can be simulated with a great precision; this is not easy with the usage of the traditional analytical approaches (Sterman 2000).

SD models can be used either in the form of decision making simulation tools, or could be used for educational purposes, these categories could be also found in the field of management and project management as will be illustrated in details in the following section.

2.5 System Dynamics in Education

2.5.1 Use of System Dynamics in Education

Looking at SD models in the field of education, two categories of models could be observed, the first category is about the simulation models that are being used as teaching aids, in a way to help the students visualising the changing behaviour over time of some topics that are being characterized by dynamic, causal, and interconnected features. The other category is about the models that are used for monitoring, analysing, and forecasting different educational system behaviour.

Examples of this category include: models that are created for investigating the low efficiency of primary education in Latin America introduced by Terlou (Terlou, et al. 1991), the models that discuss the social and the economic factors that affect the primary education enrollment (Benson, 1995), the models that are analyzing the future quality of Turkish educational system based on the budget of national ministry of education (Karadeli, et al., 2001), the models that are analyzing the educational system of Nicaragua (Altamirano, Van Daalen, 2004), the linkage between the school quality and the student's final completion grade (Hanushek, et al., 2008), the infrastructure challenge in Sub-Saharan Africa and the constraints to scale up at an affordable cost (Serge, 2009), usage of SD to model the student interest in science (Sanchez, et al., 2009), quality control system in education (Hussein, 2010), analysing the Brazilian higher education system (Borenstein, 2010), and the models that are related to modelling learning effectiveness evaluation model (Lan, et al., 2013).

The same level of categorisation could be found in the field of project management education, so we can find SD models that are used for managerial different business situations or models that are used for teaching project management itself. Briefing on these models and spotting the difference between it and the current study will come in the section below.

2.5.2 System Dynamics Applications in Project Management Education

As mentioned in the introduction chapter, project management teaching materials include an introduction of different variables, like for example quality, cost, and time control, these variables are studied through different chapters in the PM teaching materials, without being able to overlook the whole related system parts working together. This might be the exception in the real life than being the normal one. This is one of the reasons that cause getting the trainees confused when it comes to face a complicated problem that includes all of these variables working together.

SD simulation based learning environments have been rarely investigated empirically (Quadrat-Ullah, 2010). This could be seen again by going through the existing SD models in the area of project management.

The existing SD simulation based experiments in the area of project management education and training that are targeting the postgrads are coming in two main forms. The first form is related to simulation models that are being used by the decision makers and the managers in a way that will enable them to analyse a specific case and to explore the project behaviour under specific taken actions. For example; the work done by Richardson and Pugh to analyse the trade-off between the managerial decisions of allowing schedule slippage and hiring more staff (Richardson, Pugh, 1981), the work done by Maclnnis to assess the SD based management flight simulator for product development (Maclnnis, 2004), the work done by Lerch to assess the business models in the capital goods industry

(Lerch, 2010), the model of Cumenal that analysed how can organizational capacity help to clarify a project performance (Cumenal, 2011). These models helped capturing the decision making process in a rule- based knowledge rather than following procedural ways, and hence; allows for the incorporation of an explanation capability to the model itself (Abdel-Hamid, Madnick, 1989).

The second form of SD simulation based models in education are focusing only on teaching the system thinking concepts that include feedback, causality, and different relations, it only focuses on introducing and assessing these concepts without direct or indirect relation with the topic itself, and without conducting an educational assessment instrument to check the impact on the understanding ability of that topic. Because this part is about highlighting others' work in comparison with the scope of the current study, it is important to discuss samples of others' work in different categories and compare it with the current work, as in the following:

- In 2003, a study was done to evaluate the learning effectiveness of using simulation in SW project management education (Pfahl, et al., 2003). This experiment is fundamentally different from the current study as it compared between controlled group who worked with COCOMO model and an experimental group who worked with SD models, the two groups went through a lesson about PM planning and control. Some of the concerns have been discussed by the authors showing that (i) There is an unfair comparison between SD models and COCOMO, knowing the limited features that are being offered by COCOMO versus the provided features by SD, which is considered as one of the construct validity concerns, (ii) the differences between both treatments in terms of the timing, the available lesson scenarios for the participants, the absence of some information about the similarity of both pre and post assessment are all considered as part of the internal validity concerns (iii) the most important conclusion about this study is its high reliance on the subjective evaluation of the participants themselves as a part of the assessment results, this participants' qualitative data showed high scores regarding the interest, clarity and entertainment of the participants when dealing with SD (iv) there was a negative result on the assumption that was related to achieving higher scores with the participants' level of understanding when it comes to complex project dynamics, and this was explained as a result to the simple and easy nature of COCOMO compared to SD models.

- In 2007, a study was done to study the value of using stock and flow diagrams versus the text-only of microeconomics (Wheat, 2007), this work was motivated by Cohn's work at 2001 (Cohn, et al., 2001), when he compared between graphs and text instruction, which is also considered as an indirect comparison of SD based diagraming method and conventional graphical instruction. The work suggested that the feedback diagramming added value to the mere narrative way of instruction, yet, despite of the main difference between Wheat's work and the current work in terms of the scope, the methodology, and the assessment instrument, yet it was one of the author's recommendation to upgrade the design so that it allows for assessing higher learning skills.
- In 2008, a work was done to assess the impact of SD on improving project management (Lizhen, 2008). Although this study was done on one group, yet it is of high importance to the current work as it assumes from its title high resemblance, however; its focus was only related to evaluating the SD teaching impact on the dynamic development of the resources including for example, the ability of depicting the behaviour of a structure given a stock of specific quantity attached with an inflow and outflow, the ability to identify the net rates and the stock changes, and inferring the behaviour of the structure. Giving this kind of practices will affect the learners' ability to understand the system dynamic concepts in an absolute way as discussed by Lizhen in his study; especially he was assessing the pre-post improvement skills of one group. However, there is still missing work related to the impact of SD on improving the learners' skills of project management topic itself and not only the dynamic features and feedback concepts in general.
- In 2010, a study was done to explore the effect of SD approach on understanding the causal relationship skills in science education (Nuhoglu, 2010). The study targeted the middle school students, and focused on teaching science using SD. Although it addressed different target group, and has been applied on different topic, however; the current work benefited from

its design methodology and the details of the assessment instrument in light of the guidelines of the constructivist school,

- In 2010, another study was done about the usage of SD in teaching PM (Quadrat-Ullah, 2010), it assessed the effectiveness of SD based interactive learning environment, however it depends on the nature of the action experiment using one controlled group, not two groups as with the current case, and it relies on the sole group feedback regarding the user interface, the user manual, the simulation assignment, the team collaboration, and their insights about the simulation added learning benefits. So again it was more about subjective analysis about general insights rather than exact analysis about learning skills.

These experiments focused on assessing the gained skills of system thinking such as understanding the causality, feedback, and behaviour over time on its own, lacking the part of assessing the learning skills that are related to the topic itself which in these cases was the project management.

In 2007, a survey has been done about the use of SD to understand and improve PM (Lyneis, et al., 2007), this survey categorized the work done in this area into the following categories, (i) exploring the theory development and the primary causes behind the project dynamics, (ii) guidance on improving PM education and its applications, these categories highlighted the importance of having published work that covers the lessons learned of success stories and the assessment techniques that were used, This is why, the rare of the empirical work to assess the effectiveness of SD in project management education was the trigger toward setting out this study.

2.6 Conclusion

This chapter reviewed different overlapped areas that lead to the focus of the study, which is the impact of using SD as a simulation technique and the teaching challenges of a complex topic such as PM. The chapter started with the current existing PM approaches, statistics about the failed projects and the reasons behind this failure. The focus has been done on the reasons that are related to the required skills, and how are the existing educational and training channels preparing these skills from curriculum and teaching delivery lenses. Then, a revision was done about the role of simulation on learning, how it could help in addressing the challenges of discussing a complex topic such as PM, and what kind of different simulation techniques are there, and how to select the used technique. Then the focus moved towards the SD as one of these simulation techniques, discussing its key elements, its previous work in the field of education in general, in the field of PM education in specific, and how this study is different from the similar experiments. Recalling what has been said about the expansion role of simulation in education, being derived from its focus on building the required competencies (Damassa, et al., 2010). The question now is how to set an experimental approach that can assess the impact simulation based delivery techniques on the learning process.

The following chapter will present in light of the research hypothesis, the research method that will be followed to answer the research main questions.

Chapter 3 Research Methods

3.0 Overview

There are various experimental studies that have been conducted to incorporate simulation tools as a part of PM education (Abdel-Hamid, Madnick, 1991; Lyneis, Ford, 2007; Shtub, 2010; Neely, Tucker, 2012). These studies found that the static causal thinking way could be detrimental to the success of the managers being trained; they must rather adopt multi-causal or systems thinking (Abdel-Hamid, Madnick, 1991; Lewis, 2007; Kordos, 2010).

This experimental study will try to answer the causal research question - does something cause an effect? Does SD teaching approach will cause improvement in understanding skills of the taught subject. In this research, the causal relation being investigated is whether teaching using SD can improve students' project management learning and skills acquisition and lead to higher student achievement or not. Answering this causal relation requires conducting learning experiment. There are various types of experiments, for example there is the type of true experiment, or quasi-experiment, or single subject experiment (Cohen, et. al, 2007). Detailed discussion about the three categories and which experiment design selected for this study will be covered in details in this chapter.

The aim of this chapter is to present the research questions, hypothesis and its underlying rationale, the research strategy roadmap that will be followed, the types of the research experiments and the selected type for this study, and the research validity concerns along with the taken actions that help maximizing the degree of experiment's validity.

3.1 Research Questions and Hypothesis

The study tries to answer a set of questions that include the following:

- Can SD-teaching based improve the learning skills of a complex topic such as project management?
- What kind of complexity, and how to map it to learning skills?
- How to empirically assess the level of improvement in these skills?

The research hypothesis proposes that complex project management topics that are characterized by dynamic interacting variables, when explained to postgraduate learners using SD simulations will lead to:

- Achieving higher scores in the post-assessment test.
- Better qualitative and quantitative results through the post-assessment instrument, which will be designed to include multiple choice and content analysis questions, that are related to the selected taught topic in project management.
- Improving the learning subjects' skills that are related to the understanding, analyzing, and applying the project management principles.

3.1.1 Derivation of Hypothesis

How to help a project manager to understand and appreciate the complexity of a project is an important issue in PM education today (Lizhen, 2008; Shtub, 2010). In section 2.1.2 and section 2.1.3, a discussion was made about the growing need for well-trained project managers, the statistics of the failed projects, and the need to review the existing PM teaching delivery methods (Mengel, Thomas, 2008). As explained in sections 2.2.1 and 2.2.2, indicators have shown that project managers trained through the traditional methods lose the ability to practically transfer what they have learned to real situations, which usually extends beyond the well-organized classroom exams and cases (Shizhao, 2006; Shtub, 2010). Most of the project managers have problems when dealing with the complex features of projects, and struggling to make decisions that involve consistent trade-offs (Mengel, Thomas, 2008).

In Egypt; throughout the PM classes that I've been working with, students in most of the cases, have problems in practicing what they have studied. They may follow the taught mathematical procedures and theories, they may be able to complete the taught equations and formulas, and they may also be able to achieve high assessment scores in their final examinations, but this has little to do with their understanding of PM system behaviour when it involves more than one affecting variable, causalities and dynamics relations. This could be seen when observing their answers to two different questions, one is direct and related to applying an equation to get the results, and the other is about analyzing the underlying relations that led to these results. Getting high score in the first one is not usually related to their answer in the second one. Having delivered the key concepts, it would be expected that the students would be able to better analyze complicated situations, but this does not happen and leads to poor understanding and minimal retention. This is why it is important to look for different supporting ways that could help the students to deal with the complex systems, try out different scenarios of behaviours, so that they can get closer to the real life situations.

The fact that SD is characterized by its ability to reveal interrelations, variations and exploring behaviour over time, which are getting stretched to its maximum in dynamic complex systems (Kopainsky, Saldarriaga, 2012; Jensen, 2005; Rouwette, et al., 2004; Sterman, 1989a). This suggests SD as a potential supporting method for helping the students to improve their understanding about complex systems in the field of project management, which is the aim of this study.

3.1.2 Intended Research Contribution

The research intends to contribute in assessing the impact of using SD teaching based approach in the area of project management education, and explore its impact based on an experimental study that includes three formative experimental designs; the experiment doesn't only include the teaching of the systems thinking concepts, but will integrate it with a topic that is being characterized as complicated one, which is in the case of this research; the project management.

Also, the study aims at showing in practice how SD's commitment to mathematical relations is not against the relational ontology, and defends its capabilities through practical assessment of SD impact on the ground that will contribute in enriching this area of research.

The research will also provide a set of guidelines to the educators of the project management, and the researchers who are interested in the field of simulation using SD in the project management teaching field, these guidelines will be summarized from the resulted observations from the different phases of the experiment and the feedback of the participants in this experiment.

The study also, will contribute in meeting one of the main national educational challenges in Egypt which is about preparing project managers, through the design, the implementation, and the assessment of a practical delivery approach using SD simulation technique.

3.2 Overview of the Research Strategy and Design

To test the hypothesis, an experiment will be conducted with two groups of participants to assess the impact of SD on the learners' learning skills.

The following figure, Fig. (6), the roadmap of the current chapter will be portrayed. It shows that the chapter will include these main sections; the first section is about the type of the educational experiments and the chosen type for implementation in this research; followed by the formative rounds of pilot experiment till reaching the main study; the second section is about the deployment details that covers the selection of the content and the assessment technique; and the final section is about the validity and the reliability considerations that have been taken and considered during this study.

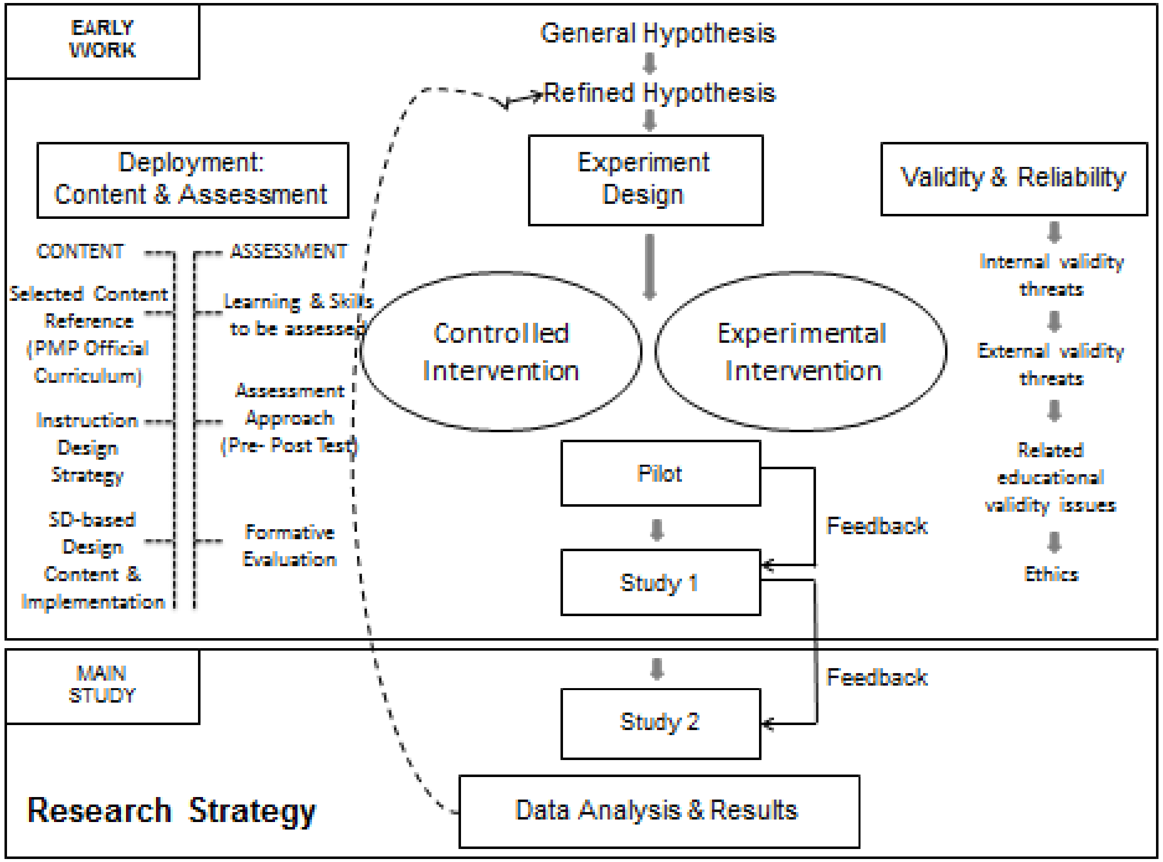


Figure (6): Research Method Roadmap

3.3 Experimental Methods in Education Research

The following experimental methods are selected as the mostly used ones by the instructional technology researchers (Ross, et al., 2008) to be discussed.

3.3.1 True Experiment Design

The selected type of experiments for this study is the true experiment design, where subjects will be assigned randomly; one variable can be treated and tested. Having a viable control group with proper randomness of subjects nominate the true experiment to be one of the commonly used experiments and with mostly validated results.

What distinguishes the true experiment from less powerful designs is the random assignment of subjects to the treatments or the experiments, thereby eliminating any systematic error that might be associated with using intact groups. The two (or more) groups are then subjected to identical environmental conditions, while being exposed to different treatments (Ross, et al., 2008; Ross, Morrison, 2004).

Arguments about the true experiments design, are mainly regarding how viable the control group will be, how accurately setting the experiment condition that will guarantee for the sole independent variable under manipulation and testing, how to control the other confounding variables.

However, once securing the previous factors, the true experiment is recommended for its valid results that could be easily statistically assessed.

The current study will follow this experiment type, with two groups of participants, further details about the taken actions for insuring the experiment validity will be discussed in section 3.6 of the validity.

3.3.2 Quasi Experiment Design

This is a type of experiments where assigning of subjects to the treatments is lacking randomness. Such experiments are applied where subjects are already belonging to specific treatments. This type is useful when it is not easy to apply randomization or conducting pre-selection like for example with the school-based researches, where the classes are already formed at the starting of the academic year (Ross, et al. 1991), although it minimizes the needed time and resources of the experiment, however; without randomisation, statistical results cannot be generalized and sometimes could be meaningless. In most of the cases, the use of pretesting or analysis of prior achievement is being used to establish group equivalence.

3.3.3 Single-Subject Experiment Design

Another type of experiments is the Single-Subject experiment (Gliner, Morgan, 2000), where a single case is being studied and exposed to a varying level of independent variable over a period of time. This type of experiments is highly flexible, allow for highlighting on single-subject differences, and of course minimize of the researcher or counsellor bias. On the other side, major criticisms towards this type of experiments and could be summarized in different points that include: having 'No rollback' or 'irreversibility', as the dependent variable once affected by the independent variable, simply this effect cannot be undone, also, this type is criticized for 'The order effect', which is the sequence of events that are affecting the resulted outcome, another criticism is about 'the chain or carry over effect', where the results from the previous stages are being propagated to the following phases.

The conclusion is; the choice of the 'True Experiment' type to be the selected design for this study is assumed to be the best option for testing the research hypothesis with the maximum level of results' validity, if taking care of the other experiment's conditions and following the validity rules. Randomisation of the participants is of high importance in providing good starting point in this regard. As seen in section 2.5.2, there are some of the SD applications in education used the one group design as with Lizhen experiment (Lizhen, 2008), however; having an experiment that amend the assessed skills to include assessing the topic knowledge skills with the system thinking skills using two groups will contribute in enriching the ground work of SD in education.

3.4 The Development of the Main Study

The experiment followed the design of 'TRUE Experiment' design type, with two groups, who followed the same instructional design with the difference of having SD intervention with the experimental group's participants. The experiment went through different rounds before reaching the final form of implementation. This section will go through these phases of trials.

3.4.1 Step 1 – Early Pilot (Pilot 1)

The first round started with a pilot experiment that was implemented on a pilot group of learners as being seen in the following Fig (7):

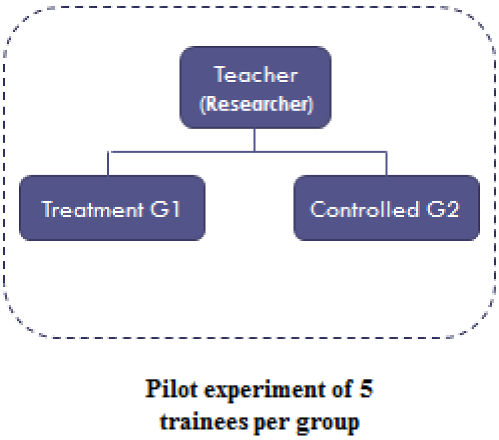


Figure (7): The Early Pilot Experiment Structure

The pilot was done on a few numbers of participants, five per each group. The goal of this round was to evaluate the appropriateness of the lesson and the usability of the models. In this round, the researcher was the same teacher, which was a point of question to the experiment validity in terms of having a natural bias toward the success of using the SD simulation. This was changed in the following round.

3.4.2 Step 2 – Pilot 2

Pilot 2 has been done after the incorporation of the resulted feedback from the early pilot experiment in Pilot 1, as well as the feedback of the other experts who contributed in the early phases of the experiment. The teacher has been prepared to eliminate the biasing effect of the researcher, also the lesson details has been amended in more gradual way. The conclusion of this second round led to preparing the lesson and the assessment instrument for the final implementation.

3.4.3 The Main Experimental Study

The main study benefited from the previous rounds of the trials to reflect on its final design, and get more valid results. Adjusting the lesson design to incorporate the usage of computer for both groups, hence; having similar learning environment was of direct impact on the validity of the experiment, also preparing the lesson in a gradual way and including set of preparatory instructions in the beginning of the lesson was of impact on controlling the lesson timing and the readiness of the participants.

The details of each of these experimental rounds, its goals, participants, procedures, and its outcome will be explained in details in Chapter 5.

3.5 The Deployment of EVM Lesson using SD simulations

3.5.1 Overview

Earned value management is the selected topic for the implementation, more details about the topic will be covered in section 4.1, chapter 4.

In developing the SD simulation based lesson for EVM, two aspects guided the lesson design. First; the original EVM text references, second; the systemic instruction design model of Dick and Carey (Dick, Carey, 1990). When thinking of the original EVM text references, and how to integrate its different knowledge areas with SD models, Dick and Carey instructional design process guidelines of 10 steps to be followed, summarized in the following:

- Identifying the learning objectives of the content and the expected learning skills by the end of the lesson, how this will be handled in the study will come in section 3.5.2.
- Conducting the instructional analysis and setting the learners' entry behaviour: Finding out the learners' performance gap, and knowing their general characteristics in terms of background, skills, and demographics will help achieving the goals of, first; making sure of the minimum learners' background that will ensure their ability to go through the experiment and not affecting the final results due to improper entry level, second; scaffolding and supporting the instruction through providing the lesson structure that the learners can build upon. How this will be handled in the study will be covered in section 3.5.3.
- Developing the lesson plan: This step has been explained in Dick and Carey model through three steps that include: first; writing the performance objectives, second; creating the blueprint of the different learning activities, and third; using this blueprint to fully develop the whole lesson content and its activities. Again, its reflection in the study will be covered in section 3.5.4.
- Evaluation; in Dick and Carey model this step consists of formative and summative evaluation. Formative evaluation is related to the trials and prototypes before the final release as described in section 3.4. Summative evaluation is about evaluating the whole program, focusing on the outcomes and the revision with respect to the validity and the impact on the further amendments; this will be presented in section 3.5.5, Then, summative evaluation is also about reviewing the final results with respect to the original hypothesis and research questions along with the feedback on the further work, this will be handled by the study in details in chapters six, seven, and eight.

Dick & Carey model has been selected for this study, as it is in systemic way follows more details than the aggregated instructional design model provided by

ADDIE design (Analysis, Design, and Development, Implementation, and Evaluation design).

3.5.2 The Aim and the Learning Objectives

It is important to specify the targeted learning objectives and to tie them with the assessment instrument. This is why; the study will use the original learning objectives of the topic as being listed in the original material of EVM, then project it to the systemic form through the SD simulations intervention.

The original learning objective of EVM in the text references is working around (Nagrecha, 2002; New Mexico University, 2006; National Aeronautics and Space Administration, 2013):

- Understanding the key concepts of different related metrics
- Monitoring, relating time phased budgets to the statement of work, and understand the project performance
- Providing the basis to capture the project progress against the base line
- Calculate and provide valid, timely, and auditable data/information for proactive management action
- Analyze and predict with a practical level of summarization for effective decision making based

Looking at these objectives from the lenses of its underlying systemic features, will lead to the following learning abilities, expected to be enabled and assessed through the study, this include:

- Seeing the dynamic relations of the underlying EVM affecting variables
- Observe and understand the behaviour over time and understanding the structure of EVM different scenarios' behaviour
- Revealing different behaviours and patterns of different EVM problems and situations
- Figuring out the chain of causal relation and understanding the tradeoffs that led to the current behaviour

In chapter 4, Table 1 and Table 2, the detailed lesson plan and activities along with its intended learning objectives will be presented. The learning objectives showed the integration between the topic knowledge skills and the systemic ability of understanding and dealing with these knowledge skills.

3.5.3. Learners' Entry Level

A pre-test has been designed to include a set of questions that will make sure of minimum entry level for the participants. The test's design will include discrete quantitative scoring questions that will give either "1" or "0" indicators for the different assessed areas, the deployment details of the pre-test will be covered in section 4.3.2, chapter 4. The demographic and the general characteristics of the participants reflected homogenous distribution for the learners in terms of age, sex, academic background, and geographical locations. The general participants' characteristics will be presented in Table 10 and Table 11 in chapter 6.

3.5.4. The Lesson Plan

Dick and Carey model described the way of designing the lesson through, stating the performance objectives, and listing the learning activities that cater for these objectives in details. The study will review the current EVM references and the challenges of using these references without any kind of simulation interference, this will come in sections 4.1.1, 4.1.2, 4.1.3, 4.1.4, and 4.1.5 in chapter 4. These sections will spot the required skills that should be integrated while designing any further simulations.

The lesson itself will be co-designed with the required assessed skills stated before, the lesson will be explained in detailed activities so that not to waste the time of the allocated class time. These detailed activities will be presented in chapter 4 in Table 1 and Table 2.

The SD models that will be used with the experimental group will be guided by the design considerations of the learning environment simulations (Swezey, 1977; Bowen, 1987; Mayer, 2004; Gagne, et al.1992) as presented in section 4.2.2, chapter 4.

3.5.5 Assessment Approach

3.5.5.1 Overview

How to assess the learners' skills is not far from what is being taught. Although we are talking here about the assessment, however it will not be in isolation from the content that has been selected. Many references are stressing on the importance of gearing all the content, its simulative models (if exist), and the assessment techniques, on the same lesson objectives. As per Cockton, we cannot frame the purpose of evaluation in absolute essential terms (Cockton, et al., 2002). This is why; the design of the post assessment will consider the learning objectives and will focus on assessing the EVM knowledge acquisition in terms of understanding and analysis skills, as stated in the main research hypothesis.

The post assessment test will include multiple choice questions, and content analysis for the qualitative type of feedback (Kopainsky, Saldarriage, 2012; Lizhen, 2008). In order to make sure that these questions will assess the understanding and analytical abilities of the learners, the assessment test should follow one of the guiding learning assessment frameworks. In education, there are different frameworks that are called learning taxonomies. The following section will discuss these taxonomies and highlight the one that will be selected for this research.

3.5.5.2 Learning Assessment Taxonomies

In learning and cognitive assessment, there are different assessment references that are called learning taxonomies; such taxonomies are helping educators to see and classify the learning goals and objectives to specific set of skills and abilities.

For the purpose of this study, and within the field of learning theories and learning assessment, there are two main taxonomies that are widely used; Bloom Taxonomy and its amended version (Anderson, Krathwohl, 2001: Appendix 5; Bloom, 1956: Appendix 4).

Both are sequencing six broad categories of learning skills that are listed below from the lower level skills to the higher level skills:

- Remember: Remembering is represented for example by defining terms, naming objects, arranging things in order, repeating statements, etc.
- Understand: Understanding is represented by being able to explain concepts, classify things into categories, describe principles, or restate information in one's own words
- Apply: Applying is represented by using knowledge and rules to solve problems, writing a report, or doing a job
- Analyze: Analyzing is represented by comparing and contrasting, criticizing, generating hypotheses, or categorizing things
- Evaluate: Evaluating is represented by making judgments, arguing and debating, defending a point of view, or making an assessment
- Create: Creating is represented by designing, planning, writing proposals, setting up experiments, drawing diagrams, building devices, and so on

Based on Bloom's taxonomy, the assessment technique for this research will be implemented. It is not of relevance to the study whether to select Bloom taxonomy or its amended version; as the main difference between both taxonomies is the ordering between the evaluation and the creation skills. Each of the taxonomies is looking at each one of these skills as higher than the other skill, and accordingly the sorting is different. This matter of sorting is irrelevant to the scope of the study, as whether to consider the evaluation skills higher than the creation skills or vice versa will not affect what is being assessed. But on the other hand, defending the choice of Bloom against its criticism is of importance, as this is the main reference of understanding and classifying the post assessment test in this study, so this criticism will be discussed from its impact perspective on the validity of the assessment.

Criticizing Bloom Taxonomy

There are serious issues that have been raised about the suitability and the relevance of Bloom taxonomy. The criticism is coming from that nature of the learning process as it is continuously changing; there are no more discrete learning activities and objectives, as all are getting more and more blurring. Bloom taxonomy on the other hand represents a very rigid controlling method over the learning behaviour. It lacks the ability to include the intuition and creativity within its three domains of knowledge, attitude, and skills (Steve, 2012).

Also applying Bloom taxonomy to the assessment will restrict the learning to a set of simple and meaningless links, and from the other side, it has nothing to add or to support with the intuitive and the creative skills. Another point regarding the overlap of the skills, as some categories overlap, for example; understanding can be exercised at many cognitive levels, learning doesn't always follow step-by-step progression, and these categories at higher levels don't adequately describe higher order thinking skills (Munzenmaier, Rubin, 2013).

Even though when Lorin Anderson, revised Bloom model and updated it with the swapping of the levels of creativity and evaluation (Anderson, Krathwohl, 2001), and another change related to the category names, are no longer nouns, but verbs. For example, 'knowledge' is now about 'understanding'. This means, objectives developed using the revised taxonomy now describe learners' thinking processes rather than behaviours (Munzenmaier, Rubin, 2013). However, the criticism of Bloom has been extended to this one, for having also similar taxonomy with the same level of rigidness when it comes to defining the learning skills.

Other alternatives exist, like the "Content-by-performance" taxonomy (Sugrue, 2002), this content by performance approach led to general prescriptions for the informational content and practice/assessment that distinguish between different types of content, for example; facts, concepts, principles, procedures, and processes. The following snapshot Fig. (8), outlines the different content types, the information it presents, and the practice or assessment way per each.

Content Type	Information to Present (Regardless of Level of Performance)	Practice/Assessment (Depending on Level of Performance)	
		Remember	Use
Fact	the fact	recognize or recall the fact	recognize or recall during task performance
Concept	the definition, critical attributes, examples, non-examples	recognize or recall the definition or attributes	Identify, classify, or create examples
Principle/Rule	the principle/rule, examples, analogies, stories	recognize, recall, or explain the principle	decide if the principle applies, predict an event, apply the principle to solve a problem
Procedure	list of steps, demonstration	recognize, recall, or reorder the steps	perform the steps
Process	description of stages, inputs, outputs, diagram, examples, stories	recognize, recall, or reorder the stages	identify origins of problems in the process; predict events in the process; solve problems in the process

Figure (8): Content-Performance Matrix (Sugrue, 2002)

Other alternative approach like “The Pure Performance”, where there is no taxonomy at all, and it is simply will assume having the same user level for all of the objectives, and the learners will practice, or be assessed based on such particular performance (Sugrue, 2002).

My argument here is, there is still no ground practical basis to follow - if we didn’t consider the existence of the other side who are supporting both of Bloom and Anderson & Krathwohl, and even with the new recommended alternatives, following either having no taxonomy or working with the previously mentioned matrix, will not reflect on the study at hands but the way of classifying the assessment, cause in the case of this study, the scope is not with creating different processes or procedures to the lesson design, otherwise this will interfere with the independent variable I am trying to assess, and it will go beyond the scope of the study.

3.5.5.3 The Post-Assessment

By the end of the class, the post-assessment will be implemented and compared between the two groups. The post-assessment test includes two types of questions, one is based on the questionnaire and the other is about feedback and responses that are coming from the participants and the experiment's tutor.

Each of the post assessment questions has been designed and tied to one of the Bloom taxonomy levels, so each of the post assessment questions has been marked or tagged to demonstrate its Bloom level that is being belonging to. So for example, this question is labeled or tagged as analytical type question, and this one is tagged as an application type question. This tagging has been done guided by Bloom taxonomy instructions on how to identify the type of the question. The overall post-assessment questions have been mapped to the learning skills that is being assumed will be improved if being introduced to SD simulation based instruction. The detailed design of the post assessment question in terms of the types and the distribution will be covered in Chapter 4, section 4.3.4.

3.6 Experiment Validity & Reliability Considerations

3.6.1. Overview

This study is about the effect of SD instruction based as the experiment independent variable. This is why it is important to control all the confounding variables that might interfere with its impact as the sole independent variable in the study. Controlling the confounding variables in a way that will secure the experiment's independent variable, nominate the validity as critical dimension to be discussed in details, in terms of what does it mean, how this meaning will be reflecting on the experiment design, and how to minimize the invalidity and maximize the validity.

What does it mean with validity will lead to the validity work reviews done by Oluwatayo and Ayodele, summarizing the definitions of the validity since the earliest of 1997 (Oluwatayo, 2012). They started with the original definition of validity, define it as: “how well the test or a meaning instrument fulfill its function”. Anastasi and Urbina use another definition as: “the degree to which a test or measuring instrument actually measures what it purports to measure” (Anastasi, Urbina, 1997), the definition has been extended by Ary, Whiston, Kaplan and Saccuzzo, McBurney and White (Ary, et al., 2002; Whiston, 2005; Kaplan, Saccuzzo, 2005; McBurney, White, 2007), as they shift the focus of the definition from the instrument only to the interpretations and the measuring of the derived scores. Validity is about following standardized procedures to hold the entire conditions constant except for the experimental variable that is called the independent variable; this standardization ensured high impact of validity and attributed confidentiality to the treatment (Ross, et al., 2004).

Reflecting these definitions on the current research, means discussing the validity of the whole experiment and not only the assessment instrument, this should include the experiment learning environment, and the scope of implementation so that to make sure of having same and equal environment that will assess the impact of SD teaching without any kind of external interference with the independent variable. The experiment and the selected content represent the surrounding environment that should be considered carefully. The Experiment factor addresses the detailed environment of the experiment including; the instruction design, the teaching methodology, the group profiles, the learning environment, and the teacher effect. All of these variables could be seen from the lens of equalizing the environment of the two groups of the experiment, hence; having one same base for both groups. This is all related to the design of the experiment that will allow for testing the hypothesis and evaluating the causal relation between the SD as a teaching tool. Most of the factors that are related to the experiment will be discussed under the internal validity section.

Beside the experiment, there is another affecting variable which is the scope of implementation (domain of application) factor. This factor is acting as a prerequisite for the research questions, as the characteristics of the selected topic, could be determinant to revealing the power of SD or not. The more dynamic and interrelated features this topic has as part of its nature, the more feasible to apply SD as a facilitating tool to this topic. So it will be important to highlight the chosen topic in terms of the encountered difficulties that will be presumably better explained through the usage of SD. This will be investigated in chapter 4.

In general there are two main types of validity that are important in research experiments: namely internal and external validity types. In addition there are four specific types of validity considered pertinent when it comes to research experiments related to educational areas, namely, content validity, criterion-related validity, construct validity, and face validity (Oluwatayo, 2012; Cohen, et al., 2007; Michael, 2002). The following will address these validity types, its relevance to the study, and the taken actions to maximize its level during the design and the implementation of the experiment.

3.6.2 Internal Validity

Internal validity refers to the likelihood that the experimental manipulation was surely responsible for the observed differences. How to make sure of having similar experiments' environment and procedures that will secure the independent variable, the following validity types have been highlighted and discussed. Threats to internal validity might come from reasons related to the selection of the participants, their history, and their maturity across the development of the experiment, design contamination, and other factors (Michael, 2002; Rommel-Esham, 2010; Cook, Campbell, 1979).

History and selection validity concerns: history means there might be unanticipated incidents that happened during the real action of the experiment (Cook, Campbell, 1979). Selection means that a bias happened in the results due to selection bias and allocation of the participants.

The current research followed the type of true experiment design, which means it deals with two groups with random assigning for the participants. This is why, the history and selection factors are not considered as a threat here, as the history factor impact is active with the experiments of one-group design, when the results will be function of the pre-post assessment test difference, also the selection bias is not valid as the randomization characteristic eliminates it from the beginning for both groups.

Maturation: During the experiment, and with time, some changes might happen to the dependent variables due to normal developmental processes, for example, subjects get tired, some quit for other reasons (Altermatt, 2014). In the case of this study, having two groups with the same conditions that will allow for same rate of development or change on the subjects' maturity make this factor not considerable, especially with such short experiment timing that makes it easy for the participants to commit themselves throughout the experiment duration. In other cases, this factor is of high importance like for example with medical research types (Taylor, Asmundson, 2007).

Statistical Regression: the effect of this factor comes as a result of the subjects' selection based on getting extreme scores in the pre-assessment test that will regress the scores and make it move toward the mean (Campbell, Stanley, 1963; Dattalo, 2008). In the experiment, this factor has been eliminated due to two reasons, first; the randomization of the participants on both groups, second: the pre-assessment test that was functioning as a pre-assessment tool for the participants' background skills to make sure of their ability to join the experiment and was not used for assigning them per specific group or as a benchmark that might affect the final post assessment scores based on high entry level.

Mortality: This threat is valid for both options; one group or two group design experiments, so dropping out any of the subjects, will affect the results of one or two group designs. Fortunately, this threat didn't happen in the experiment, as a special care was given to the conducting time of the experiment to best suit all of the subjects' agenda, hence guarantee their attendance and commitment along the whole experiment (Hale, Astolfi, 2015).

Design Contamination: contamination means diffusion of the experiment details and the information from group to another. In this experiment, this was controlled through conducting the experiment for the controlled and the experimental groups, right after each other without any time gap that might allow for the meetings or communications between both groups' participants.

Compensatory rivalry and resentful demoralization: When subjects in some treatments are treated differently and believed to be desirable, and when this becomes known to the other subjects in the other groups, social competition may motivate others to reduce or reverse the intended results. Also feelings of resentment might cause performance at abnormal low levels (Hale, Astolfi, 2015). Again, this was controlled through the following actions: First; the teacher effect: During the early pilot of implementing the research, the researcher was the person who was conducting the experiment and acted as the teacher in the same time, sometimes; the researcher intentionally or unintentionally tends to convey his beliefs to the participants, hence; affecting their results. This is why; another teacher with no SD background joined the experiment, after accepting and getting curious to figure out the impact of SD on better improving the learning process. He got prepared, and managed both groups from neutral point of view. This factor will be discussed again as it is being seen one of the ecological validity types that might affect the generalization of the study results in section 3.6.3.2.

Second; this kind of evolving emotions might not only come from different treatments by different teachers, but it might also rise from any probable incentives that might exist within the experiment and the learning conditions. This was encountered, in the early stages of the experiment, when there was a difference between the two groups in terms of the usage of the computer as a part of the learning environment. In the first pilot study, the work of the controlled group didn't include any kind of computer intervention; on the other hand, the experimental one used the computers as a must in light of their experiment's nature of using simulations that entail the need for computer. The feeling of lacking materialized object as "computer" was not a favorable difference to have. This was the reason to include the computer for both groups, as a presenting tool for the material and the related assignments and other work for the controlled group, and being used with the experiment group to practice the usage of SD simulations models. Again, equalizing the two groups in terms of the participants' sampling, their backgrounds, their allocations, and other factors, has been discussed with relevant to its validity type, i.e. ‘selection’, ‘history’, ‘statistical regression’, etc. as discussed earlier.

3.6.3 External validity

This validity type refers to the extent to which the results of the study can be generalized to the larger population (Carmines, Zeller, 1979). It could be divided into two categories:

Population Validity: This type of validity is about how representative the sample is, and how widely the findings can be applied (Bracht, Glass, 1968). In this experiment, using random selection as a fair way of selecting the experiment’s sample from a population of the Egyptian students was the key factor to maximize the probability of generalizing the results of this experiment.

Ecological Validity: This validity type refers to the degree of the results’ generalization across the following settings:

Interaction effect of testing: in some cases, the pre-assessment test interacts with the experiment itself in an affecting way on the results (sometimes, the pre-assessment test guides to act in a specific direction), hence; the results will not be applicable on the untested population (Hale, Astolfi, 2015). Again, having no impact for the pre-assessment test on the experiment itself in our case, make this factor invalid.

Interactions effect of the selection biases and the experimental treatment: sometimes, when there is no random selection, the selection of intact groups might interact with the experiment treatment, which is again not valid in the study case. For example; if subjects here were assigned to groups based on their scores, then we wouldn’t be able to generalize the results to heterogeneous abilities, which didn’t happen, as the assignment of the participants was done in a random way.

Experimenter Effect: This factor has been tackled in light of the impact of Compensatory rivalry threat on the internal validity of the experiment. Again its impact here is being referring to situations where the experimenter willfully or un-conscious awareness affecting the direction of the results. This is why, it was a recommendation and after the first pilot of this study to tackle this concern, which has been done through having another experimenter rather than the researcher.

Now moving from the internal and external validity as a general validity types, to the types of validity of importance when it comes to research experiments applied in educational areas (Oluwatayo, 2012).

3.6.4 Validity Issues Related to Educational Research Areas

3.6.4.1 Content/Logical Validity

This type of validity has been defined as how well the content of the instrument samples the kinds of things about which conclusions are to be drawn and investigated (Bracht, Glass, 1968; Newman, et al., 2011). This type of validity is concerned with the relation between both the content and the assessment and how related they are together. The relation between the learning objectives, the assessed learning skills, and the assessment instrument has been explained in section 3.5.3 and section 3.5.4, and will be re-addressed in section 4.3.4 from the implementation point of view.

3.6.4.2 Criterion-related Validity

This validity is a measure of how well one variable or set of variables predicts an outcome based on information from other variables. Criterion-related validity is where a high correlation coefficient exists between the scores on a measuring instrument and the scores on other existing instrument which is accepted as valid (Oluwatayo, 2012). For example, the student's entry exam scores might correlate with his graduation exam scores; this means that the first exam shows strong reductive validity. It relies on finding existing correlational coefficients between the scores of different measuring tests. This type of correlation is not applicable in this study, again due to the different nature of the pre-assessment test from the nature of the post-assessment test, so the pre-test has no relation with the post assessment in terms of questions or targeted skills that are being assessed, also the pre-test has no relation with the participants' performance within their groups, as it worked as an assessment for the participants' minimum knowledge prior their enrollment to the experiment, and after passing the pre-test, their allocation to any of the two groups was done randomly and not based on their pre-test's scores. Also the pre-test questions didn't guide or give any direct or indirect clues related to the post-assessment questions.

3.6.4.3 Construct Validity

It refers to whether the operational definition of a variable actually reflects the theoretical meanings of a concept, It is based on the logical relationships among the variables, so if we are assessing person's intelligence, then to have construct validity we need to correlate it with the related areas that measure for creativity, and innovation (Shiken, 2000). Again, the research is looking for the relation between SD learning based and learning skills of a complex topic, these skills have been specified in terms of the knowledge acquisition, and analysis. The lesson post assessment was designed to focus on these skills, and the lesson was designed to include activities that are related to these skills as explained in section 3.5.3 and 3.5.4 in a conceptual way, and will be presented from the implementation perspective in chapter 4, section 4.3.4.

3.6.4.4 Face Validity

The face of the presentation or the relevance of the instrument appears to measure what it claims to measure, for example, the relevance of the material/presentation, the content of the relevant instrument seems silly or not appropriate to the audience age, subject-matter expert can validate the relevance of the instrument for its intended use. Although it seems simple and some consider this validity type as a week form of validity due to its reliance on subjective judgment (Drost, 2011), but references didn't leave this validity for subjective evaluation, and put some criteria that should be followed to make sure of having instrument with proper face validity. These criteria include: the general structure, the clarity of items, correct spelling of difficult words, spacing between lines, adequacy of instructions, and attractiveness of papers used. This was considered while preparing the material that was also guided by the original references of the EVM topic, reviewed thoroughly before the final implementation, benefited from the feedback of the different iteration of the implementation of Pilot 1 and Pilot 2.

3.6.5 Research Reliability

Reliability of the research is about how consistent the measures of this research are. In other words, it is about getting almost the same results and drawing the same conclusions when repeating a test. Cohen referred to the reliability as having the same results, if the same methods used with the same sample and of course within a certain limit of experimental error or random error (Cohen, et al. 2007). There are different ways to assess the research reliability. One of them called test-retest reliability, where to conduct the test at different points of time. Reliability will be higher with less time between different points of time.

In the study, the design was including a retention test which is a replica from the post assessment, and it was assumed to have it within four weeks after the post assessment test and with the same sample of participants. This retention was not considered as one of the research reliability measures, but also was designed to measure the retention of the learning skills for the participants. However, the test encountered some problems that didn't allow for its implementation; leave it as one of the recommendation for further research areas that will help on assessing the reliability of the study results and assessing the long term retention capabilities of the learners to the acquired knowledge and skills.

3.6.6 Research Ethical Considerations

The concept of research ethics is important to be reflected in a clear way on both sides: the experimenter and the participants. From the experimenter side, it is important to share the needed information about the experiment and to make sure of the participants' willingness to adhere to the different stages of the experiment. From the participants' side, their commitment to the experiment's requirement in terms of time, and following the instructional rules is essential to conduct the study. Also, there should be a balance between what they need to know and what kind of information that they don't need to know so that not to affect the results of the experiment. As per Ruane, a question has been raised about the enough amount of information that will be needed? (Ruane, 2005). Because too much information might cause bias whether for students in the controlled group who might feel frustrated or the students of the experimental group who might be extra passionate about the experiment, in the case here, a choice has been taken to brief them about the general purpose of the experiment, to make sure of their willingness to join with no further information about who is going to take what, cause this might affect their willingness or passion about any specific option. The shared information was related to the type of the experiment, the duration, and the phases of the assessment.

3.7 Summary

The research study will follow the true experiment design to evaluate the efficacy of specific intervention; one independent variable; which is SD-based teaching methodology. A true experiment design will be used, through two groups; the control one; which is the group that will go through the traditional way of teaching with no SD exposure, and the experimental group; which is the other group that will go through the manipulated way of teaching using SD, and assessing the learners from both groups' skills mapped to Bloom taxonomy.

Many threats to research validity and reliability have been categorized by (Oluwatayo, 2012) as:

- Conceptual and design bias: this bias comes due to any faulty logic by the researcher that will lead to faulty conceptualization in the problem, the subsequent solving approach design, results, and conclusion.
- Sampling bias: this happened when the selected sample does not represent the population of interest, or as previously discussed with the existence of any bias in assigning the samples to any of the two groups.
- Process bias: this comes as a result to the previously biased or faulty decisions leading to distorted data and results.

Maximizing the validity of the experimental research is proportionally related to the attenuation of threats to both validity and reliability. As this experiment is a study of a cause and effect, manipulating one variable, and as possible as we can keep the surrounding interfering variables constant (Cohen, et al., 2007; Borrego, et al., 2009), this was done through creating similar learning environment, taking care of what is being assessed, and how it will be assessed, sampling mechanisms for the participants and how to secure their commitment and behaviour during the experiment as being discussed.

Increasing the level of validity was discussed from different views; one of them was related to the experimental methods' points of criticisms. These criticisms are highlighting some potential disadvantages that include; the probability of inhibiting natural behaviour, low finding generalization to the real world, low ecological validity, bias of selection, and the experimenter bias (Barnes, et al. 2012). All of these disadvantages have been discussed in light of the validity challenges and threats.

There is no hundred percent valid experiment, but having a reference about the threats of experiments and how to secure it as much as possible, and how to take into considerations the factors that will increase its validity, is the key to minimize the invalidity of the experiment. The question now is how to implement and assess the results of this experiment in a way that will quantify the impact of using SD simulation in teaching project management.

Chapter 4: Design of Earned Value Management Lessons using System Dynamics

4.0 Overview

This chapter sheds a light on the choice of Earned Value Management (EVM) to be delivered through SD, then goes to describe the design of adapting the selected topic through this method of delivery, and present a snapshot of the SD simulation based lessons prototype.

4.1 Earned Value Management (EVM)

EVM has been used since the 1960's by the department of Defence, USA, as a standard method of measuring and projecting the performance of projects, and then later used by the government institutes and the private industry as a powerful project management tool (Chen, Zhang, 2012; NDIA, 2015).

Simply the word 'earned' refers to the physical 'acquired or achieved' and as it implies from its meaning Earned Value is something has been gained in light of some efforts, time, and money.

Earned Value is being used as a measuring progress tool for projects' performance, providing three main functions (Wilkens, 1999):

- First, it is a uniform unit of measure for total project progress or for any sub-element of the project.
- Second, it is a consistent method for analysis of project progress and performance.
- Third, it is a basis for cost performance analysis of a project.

EVM as a topic integrates naturally between different project's variables, which are the scope of the project, the allocated budget, and the estimated duration. Having most of the projects with a dynamic interacting related activities; make it a norm rather than an exception to have these initially planned dimensions of scoping, budget, and timing in a continuous state of change. On the other hand, modelling and simulation using SD potentials lies on its contribution to our understanding of both the structure and the behaviour of a complex dynamic system, which led to better understanding of the task system (Conant, Ashby, 1970; Qudrat-Ullah, 2010). This matching between the natural shape of EVM as a complex topic and the potentials of SD to address such challenge was the reason behind the selection of it as the topic of implementation for this research study.

4.1.1 An Overview of EVM Topic

EVM provides the beginning for analyzing the projects' cost performance. Through providing the planned cost of the project being studied at any point of time, EVM can monitor the project's performance in terms of the budget versus the initial target as well as forecasting the expected performance of the project in light of these given inputs.

For example, if being discussed one of the project's values and having an equal planned value estimate to the actual cost value, can we assure secured cost performance in light of this given input? Sometimes, this simple input can give a perception about having a good shape project that will finish as planned in terms of budget, however; if we tried to take into account the physical progress, here we can see the whole picture, and this safe picture of the project's performance might be changing accordingly.

4.1.2 EVM: Key Structures and Components

EVM relies on three main basic elements (Humphreys, 2002, Deltek, 2009):

- Planned Value (PV): This element refers to the authorized budget assigned to work to be accomplished for any activity or work breakdown structure component. It includes the detailed authorized work, plus the budget for such authorized work over the life of the project. Sometimes, PV is being called Budgeted Cost of Work Scheduled (BCWS)
- Actual Cost (AC): This element refers to the total actual cost recorded in accomplished performed component to date. Sometimes, AC is being called Actual Cost of Work Performed (ACWP)

- Earned Value (EV): This is the value of work performed. This is the authorized work that has been completed plus the authorized budget for such completed work. Measuring the EV value, must be related to the PV.
  Sometimes, EV is being called the Budgeted Cost of Work performed (BCWP). Having at any time of the project the: 'planned work', 'the actual work' and 'the cost of the actual work'. It allows making the full analysis of our project progress and performance in light of the project's performance indices and variances and also predicting the projects' future performance trends, following the formulas below.
- Schedule Variance (SV) is a measure of schedule performance on a project and useful metric to indicate if the project is falling behind the schedule.
  A comparison of amount of work performed during a given period of time to what was scheduled to be performed, if resulted into a negative variance this means the project is behind.
  SV = EV – PV
- Cost Variance (CV) is a measure of cost performance on a project; it is a useful metric to indicate if the project is over the planned budget. A comparison of the budgeted cost of work performed with the actual cost, if resulted into a negative variance means the project is over budget.
  CV = EV – AC. (Nagrecha, 2002)

SV and CV could be converted to efficiency indicators to give a measure of the actual progress compared to the progress planned, as well as a measure of the value of work completed compared to the actual cost or progress made on the project, following the coming formulas (Fleming, Koppelman, 2009):

Schedule Performance Indicator (SPI): SPI = EV / PV: If SPI<1 this means project is behind schedule or the work is being completed slower than planned.

Cost Performance Indicator (CPI): CPI = EV / AC: if CPI<1 this means the value of the work that has been accomplished is less than the amount of money spent.

Cost Schedule Index (CSI): CSI=CPI x SPI: The further CSI is from 1.0, the less likely project recovery becomes. The following Fig. (9) Represents the previously mentioned values of different Earned Value Elements for one of the projects (Crowther, 1999; Nagrecha, 2002).

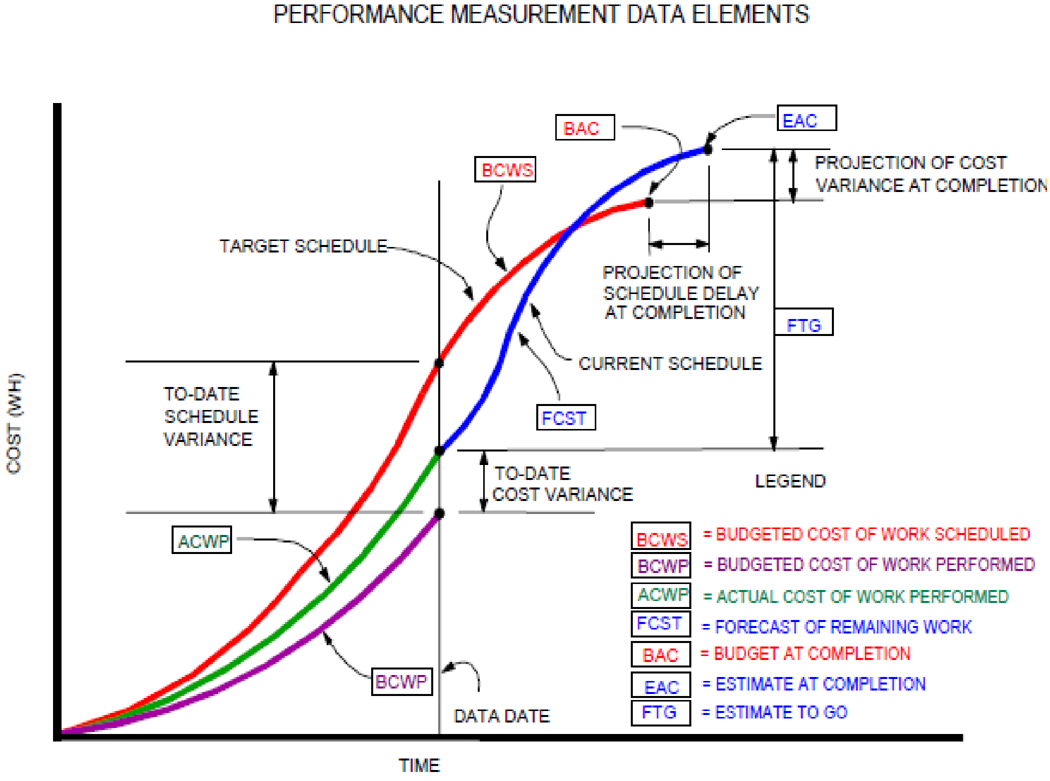


Figure (9) Earned Value Elements. (Wilkens, 1999)

One of the examples that showed how to calculate the EVM different elements for one of the real project scenarios is included in Appendix 8.

As being seen from the previously detailed elements of EVM, it deals with different variables that indicate meaningful insights about the project's performance. Usually this topic is being handled in a very narrative structures way, assessed through a direct application for the underlying series of equations, which in most of the cases, doesn't not indicate whether these right answer are due to understanding or mere reflection of good memorization.

4.1.3 Presentations of EVM in Project Management References

There are various tutorials and references for EVM that are available either on internet, and text books. However; the official representation in PMBoK, is presented through a series of textual explanation including two graphs for presenting the EVM different elements including: AC, EV, PV, and budget at completion and another graph related to the projection of the cost performance that must be achieved through the remaining work to achieve the previously specified management goal.

In a direct structured way, the material presents the details of EVM as in below:

- The definition of Earned Value Management
- The main three elements of EVM (PV, AC, EV)
- The main elements of variances (SV, CV)
- The variances efficiency indicators (SPI, CPI)
- Plotting EV data using S-graph
- A textual introduction about ‘forecasting, its underlying variables, and how to calculate them
- The projection of the cost performance, and a graph presenting the ‘to-complete work’ indicator
- Finally, concluded with almost one page of reviews

Full detailed snapshot attached in (Appendix 9).

4.1.4 The Delivery of EVM in Project Management References

EVM in the official references is being introduced through text presentation that include full details of its key variables, and the underlying formulas and equations that calculate these variables as well as its meaning and implication on the status of the progress of the project. Within the real classes, usually the tutor supports this topic with different case studies and examples, these examples are working around giving a sample from the real life scenarios and asking the learners to drive the different EVM variables and comment on the resulted data.

Usually, the students can either memorize the pre-set equations or just look back at the set of formulas to follow and come out with the required results. However, their scores are not proportionally related to the level of their understanding. For example, some of the students think of the planned value (PV) as the integrated value of activity rather than of time, simply the reason is because they didn't get the idea of dynamic relation versus time (Lizhen, 2008).

4.1.5 Challenges of EVM to Learners and Nomination for SD Simulation

It is important to teach the prospect project managers how to manage the project cost and the schedule performance in an integral way and not from isolated point of view. Earned value Management (EVM) tool provides this linked picture between the project's target with the required cost and within the allocated budget. In the work of (Shechet, Patton, 2007), he highlighted the importance of training the agencies' key managers on EVM, especially when used for the first time, not only from the process perspective, but also from the behavioural style. This emphasis is being of higher importance when it comes to teach EVM to fresher or undergrad. The EVM is a natural easy technique to follow, but not an easy way to understand and analyze the underlying meaning of numbers, and relations.

Grasping the underlying meaning of EVM variables and recalling it in real life scenarios, is more complicated than being presented in a simple textual structures way, as explained in the previous section. As these ways of text representation or with the case scenarios, it does not provide deep insights about the recursion, relations, causalities that affect the way of interaction between these variables, and consequently, the ability to imagine the different ways of project behaviour scenarios under different input of manipulations. Also, conveying the meaning of interrelated variables, and the way they are acting to draw the future scenario of the projects in a condensed list of equations, reduce and limit automatically the expected learning outcomes and limit them to the narrow boundaries of the application skills layer.

In the previous section, the listing way of the underlying topic, reflects actually the delivery approach inside the classroom that in most of the best cases might be attached with practical examples for applications. This listing way of presentation for causal related dynamic variables conclude the main challenge of learning EVM. Having this nature of complex interacted dynamic topic with poor delivery inside classes, was the reason to nominate it for implementation to the current study. More details about EVM will come in Appendix 8.

The text in red in Fig. (10) Illustrated the progress so far towards the fulfilment of the research strategy, and highlight using the red oval around the design of the lesson, that will come in the next section.

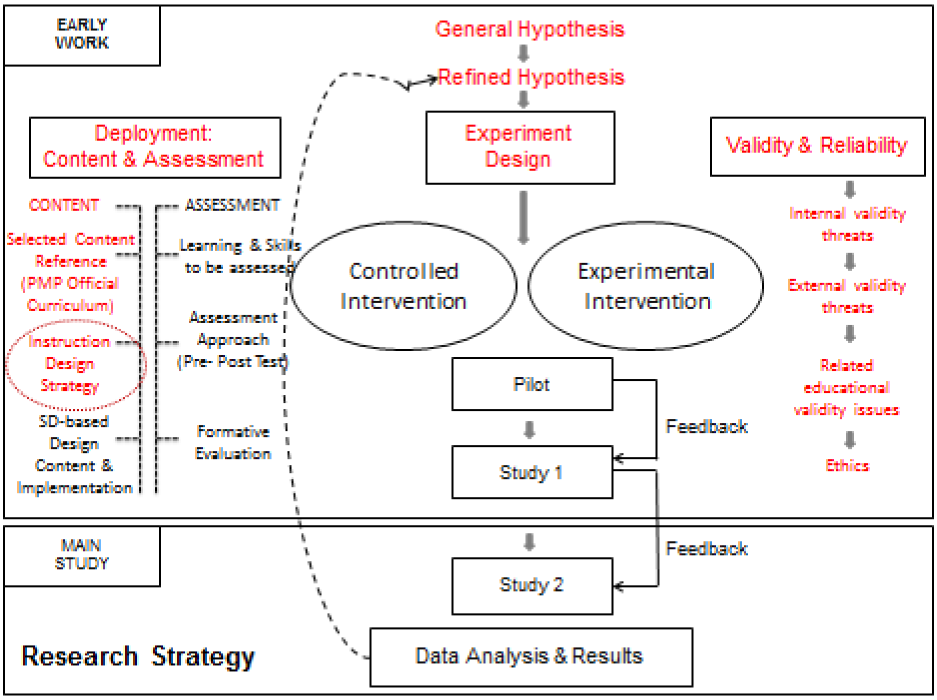


Figure (10) Fulfilment of Research Strategy up to the Lesson Design

4.2 Design of Earned Value Management Lessons

4.2.1 Background and Design Principles

The reason for the design of SD simulations to deliver EVM, is to assess the presuming abilities of SD as a simulation tool for achieving better understanding of a topic featured with interacting dynamic changes that affect its behaviour, and trying to explore the impact of this new delivery approach on aiding the learners to visualize (monitor), control, and reflect back based on their observations.

In this case, having the SD simulation will complement the formal teaching delivery through providing interactive learning environment, it will provide us with three main components (i) Domain based simulated to allow experiential learning environment properly designed for the users (ii) Interactive user interface, (iii) Human facilitator for conducting the briefing and debriefing (Davidsen, 2000; Zydney, 2010; Qudrat-Ullah, 2010; Homer, Hirsch, 2006; Kriz, 2003). These points will lead to the talk about the design consideration of the interactive learning simulation environments.

4.2.2 Simulation Based Learning Environment Design Considerations & its Reflection on the Lesson Simulation's Design

The learning environment simulations guidelines highlight the following list of considerations (Swezey, 1977-78; Bowen, 1987; Mayer, 2004; Gagne, et al., 1992):

- Conducting the experiment within a safe environment
- Providing enough processing time with a clear summary providing a cognitive map of the experience
- Representing real situations
- Providing the simulation's user with certain controls over the system/problem/situation

Other considerations have been set to minimize the cognitive load of the learners that affect their learning abilities as in the following:

- Active Integration: this means how to relate the learner to the representations of the complex situation, as for example, to use names that are similar to the real problem variables. This has been reflected in the used models in the experiment (such as the software development progressive model stating variables, stocks and descriptors named "Developers", "Functions Developed", "Developers hiring rate", "Developers attrition" as illustrated from the objects' names in the following snapshot of Fig (11).

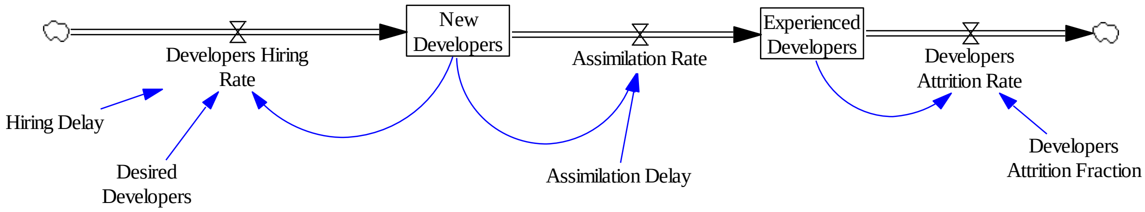


Figure (11): Active Integration of Objects' Names

- Model Progression: sometimes this property is being referred to gradualism, which is about starting with a simple representation or model and slowly increases its complexity. So for example, in the current experiment, the models have been designed to grow gradually. As illustrated below the model in Fig (12.1) and in Fig. (12.2) has been outlined with a small case; simply like a model describing the number of software developers in a company and how it varies with the inflow and outflow of employees. Afterwards the model progresses to reach a nearly full simulation of a software development cycle. The following snapshot in Fig (12.1) shows the initial model as started in the beginning of the instructional design showing only a simple stock and flow relationship between the hiring rate of the developers and the stock of the available developers in the company at specific points in time.

Figure (12.1): Gradualism A

The next diagram – depicted in Fig (12.2) shows another instruction activity where the developers' attrition rate is added to the cycle of recruitment, and contributing to a relationship that varies based on the main variables (Hiring and Attrition).

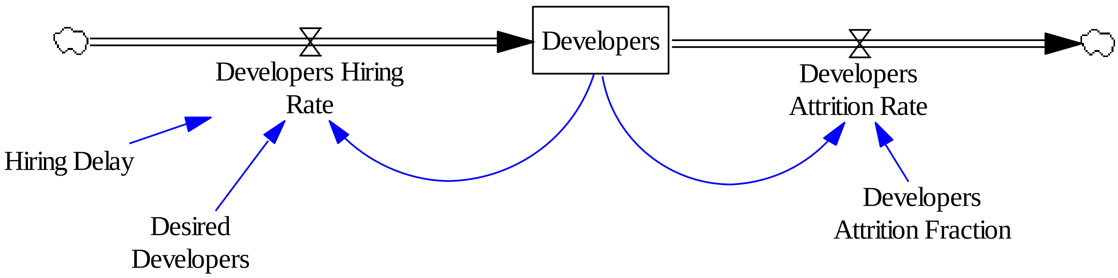


Figure (12.2): Gradualism B

Moving on; the next model represented in Fig (13) comes at the conclusion of the models' sequence, outlining the complete software development eco system with the integration of all the elements. This model brings forward the most realistic and detailed description of the system under study.

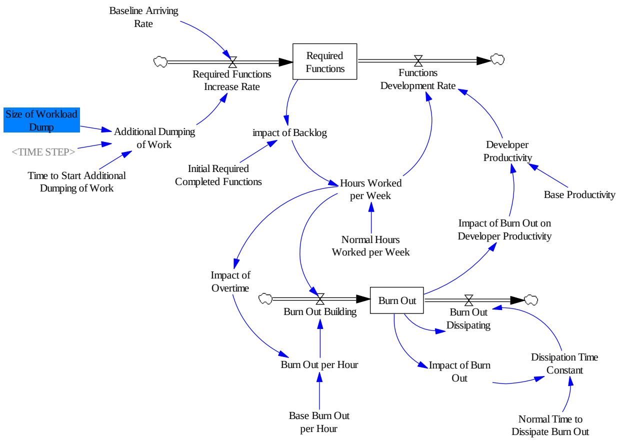


Figure (13): Gradualism C

- Curriculum Integration: This property refers to the usage of the model as a part of the curriculum and not as a separate box. In the design of the current experiment, the design followed the original curriculum of the Earned Value Management text references and the models have been used as integral parts of the referred subtopics.

- Provide repetitive practice and feedback: Subjects interfaced with the models were allowed to practice after each and every different activity to ensure that the information is solidified and consolidated with the guidance of the teacher.
- Scaffolding and guidance: sometimes, learners found it difficult to deal with new learning environment as simulation and might be difficult for them to try, explore, analyse, and generate hypothesis (De Jong, Joolingen, 1998). This is why, Mayer argued that for effective learning using simulation, it needs to be carefully guided, mentored or scaffold, in a way that will ensure useful construction for the knowledge along the way (Mayer, 2004).

Shang described three categories of learning support scaffolds, which is similar to the human tutor support guidelines recommended by Davidson and Grobler through which they categorized it into pre-task, in-task and post task level support (Davidsen, Spector, 1997; Shang, et al., 2004; Gröbler, et al., 2000; Qudrat-Ullah, 2010) as:

- Experimental guiding: this kind of support involves guiding the user's inquiring skills; as subjects had no previous knowledge of the selected topic (EVM) or the domain of simulation; it was necessary that they are not left unguided. In the experiment of the study and with the subjects of the experimental group, the lecturer followed the methodology of explaining, guiding and ensuring that they had the required guidance and making the task goals clear before getting involved with the models, as to where to look and what to look at then prompting them with questions to let them try, and stimulate their deductive powers, then leave them to do the deduction and inference.
- Interpretive guiding: This kind of support is about providing the user with the background information to facilitate their understanding about the problem. Actually this is a point that has been handled through two ways, the pre-assessment test that secures minimum level of understanding as a prerequisite to go through the experiment, as well as the introductory part about the topic that will be studied in the form of normal instructional text prior to any practicing. Subjects were also introduced to new real life

concepts that helped their understanding and comprehension of the real life cases, such as the introduction of concepts like “Assimilation delay” that is rarely instructed in formal education. Also during each sub model, lecturer made sure to allow the students to reflect on their understanding and making sure of quickly highlighting the goals of the upcoming tasks.

- Reflective guiding: This kind of support is about providing the user with different ways to help them draw conclusions. This kind of support is being recommended by the researchers as it improves the learners’ performance via providing them the opportunity to reflect on their experience with the task (Buda, 2009; Davidsen, 2000; Beauchamp, Kennewell, 2010; Qudrat-Ullah, 2010) i.e. to give them a way to record their data, through making observations, hence reducing the amount of information the user needs to keep in a short term memory. Here in the current experiment, the subjects of the experimental group were encouraged and guided to keep simulation runs and compare simulation results under different input variables and assumed scenarios. This helped the users to compare and relate cause and effect relations under different run conditions and led them to make their own conclusions based on their observations. Discussion at the end was done by the tutor, to discuss different thoughts and scenarios as will be explained in details with the lesson plan in the next sections.

The participants don’t need to understand the detailed structure of SD, or how to build the models itself; in this case, they need to be aware of the SD components, and its meaning, so that they can understand the language of representing systems and understanding their behaviour.

4.2.3 Co-Design of the Learning and Assessment Context

The current study, explores the potentials of SD on achieving higher level of understanding of the EVM topic, so the assessment will be about both (i) the system thinking skills that are related to the dynamics, accumulation, and causality as with the work of (Lizhen, 2008), and (ii) will assess the usage of these features on achieving better understanding on the EVM itself.

This is why; it was presented in section 3.7.2.1 the relation between the formal learning objectives of EVM and its underlying systemic challenge that will be looked at. The following table 1 will present this relation:

Table 1: Learning Objectives and Underlying Systemic Challenges

EVM Learning Objectives	EVM LO's Underlying Systemic Features
• Understanding the key concepts of different related metrics	• Understand the dynamic relations behaviour over time, of the EVM underlying affecting structure based on a set of EVM metrics,
• Monitoring, relating time phased budgets to the statement of work, and understand the project performance	• Revealing different behaviours and patterns of different scenarios for these metrics,
• Providing the basis to capture the project progress against the base line	• Figuring out and explaining the tradeoffs, and the chain of causal relation that led to the current behaviour,
• Calculating and providing valid, timely, and auditable data/information for proactive management action • Analyzing and predicting with a practical level of summarization for effective decision making based.	• Having an understandable overall look at the whole project in terms of applying the guiding formulas and understanding to the results of these formulas.

The following table 2 presents the whole lesson plan including the learning and the assessment activities, after mapping it to the previously explained learning objectives.

Table 2: Lesson and Assessment Plan

Activity		LO
Setting the Environment: Preparing the lab environment with the needed software, as result from Pilot 1 (Controlled group's PCs have the PowerPoint and Office, Experimental group's PCs have SD software and the models)		
Induction: Intro about the whole experiment flow		
Pre Assessment: A pre assessment is conducted for subjects gauging their knowledge in the basic areas of Project Management, Time-Cost trade-off and value of money.		
A. EVM Basic Concepts (For Both Groups)		
A.1	Introduction to Project management and the importance of the discipline in day to day life as well as the basic definitions of projects.	• Importance of Studying PM • Defining a project
A.2	Introduction to the basic concepts of EVM including its different uses. This section also includes the basic definitions in EVM such as the EV, SV, CV, AC, SPI and CPI. The multidimensional nature of EVM and involvement of Time, Cost and Scope	• Define EVM • Outline Basic Concepts • Understanding the underlying concepts of EVM and how EVM works
A.3	The different formulas used in the application of basic EVM including the formula to calculate CV, SV, CPI, SPI.	• Ability to apply simple formula in simple contexts
A.4	Formula Basics Example	

B. EVM Application Using SD and MS Excel Simulations		
Coaching prior resuming for both cases		
B.1 Exp.[1]	Explanation of what is modelling and the importance of SD in modelling real life scenarios and projects that are of high complexity	• Defining and practicing SD and modelling
B.2 Exp.	Modelling a simple system example and outlining the relations between a simple inflow and stock and how the relation changes over time. In this section; subjects were introduced to the concept of stock and flow in an analogous way to A.4 example and the mapping of those two concepts to the value of work being done.	• Understanding stock and flow. • Assessing performance over time.
B.3 Exp.	**Practical Activities (reinforcement):** Subjects are given the models and are induced to manipulate the different variables and observe the relation between the inflow to the model (Represented by a faucet inflow to a bathtub) and the stock level (Represented by a bathtub). Subjects were given exploratory questions tackling hypothetical assumptions and changes in	• Application to real life context. • Understanding EVM application. • Understanding Trade-off relationships between various components

[1] Experimental

	time, quantity and capacity. Subjects were then encouraged to infer the relations between the different system components and their representation in terms of earned value.	
B.1 Ctrl.[2]	Reflecting on a simple theoretical example of a small project that gets affected by simple forces that impact performance either positively or negatively. Subjects are given exploratory questions to probe how the different variables affect Earned Value Metrics of the project.	• Relating the EVM concepts to real life simple context • Understanding how real life situations and scenarios affect EVM metrics
B.2 Ctrl.	Subjects are given an MS Excel sheet containing the calculations of one of the scenarios of the project. Subjects are then asked to manipulate the scenario and determine which conditions are best to achieve optimum project performance. This is applied to a simple project with a minimal amount of variables.	• Understanding how changes in variables cascade to affect project performance.
C. Progressive EVM Examples (Corporate Related Examples)		
C.1 Exp.	Subjects are then introduced to several SD models in a gradual	• Enforcing EVM concepts • Understanding EV performance

[2] Control

	model starting with adding an outflow to the previously introduced "Stock and In-flow model". Models gradually add real-life complex additions such as recruitment of employees in a company entailing recruitment delays then gradually moving to attrition, assimilation delays, performance drops and rework.	in real life concepts • Applying EVM concepts
C.2 Exp.	Practical activities (reinforcement): Participants are given exploratory questions while being able to manipulate the different model variables inferring the relationships between the mode's different components as well as the impact of variable changes on Earned Value metrics.	• Application on learned concepts
C.1 Ctrl.	Subjects are given a complete EVM example in paper form and are guided through solving the current example. Subjects then reflect on the example and inspect the different variables affecting the project performance and its results.	• Reinforcing EVM application in real life problems.
C.2 Ctrl	Practical Assessment (using pen and paper): Participants are given exploratory questions trying to practice more on written	• Application on learned concepts

	scenarios	
Post-Assessment		
Post Assessment: A post assessment was conducted in order to gauge the participant's ability in the different tackled areas. The post assessment includes questions on value and earned value concepts as well as their ability to apply Earned Value concepts to real life situations, infer relations between different earned value components and the impact of inputs and outputs on EVM metrics.		

4.2.4 Description of the Simulation Models

As described in section 3.9, the lesson structure with its matching models has developed and changed over the time and as per the feedback from the early pilots of the implementation. The following sections present both models; those of the early experiment titled as "pre-final simulation models" and those related to the final experiment, titled as "final-models".

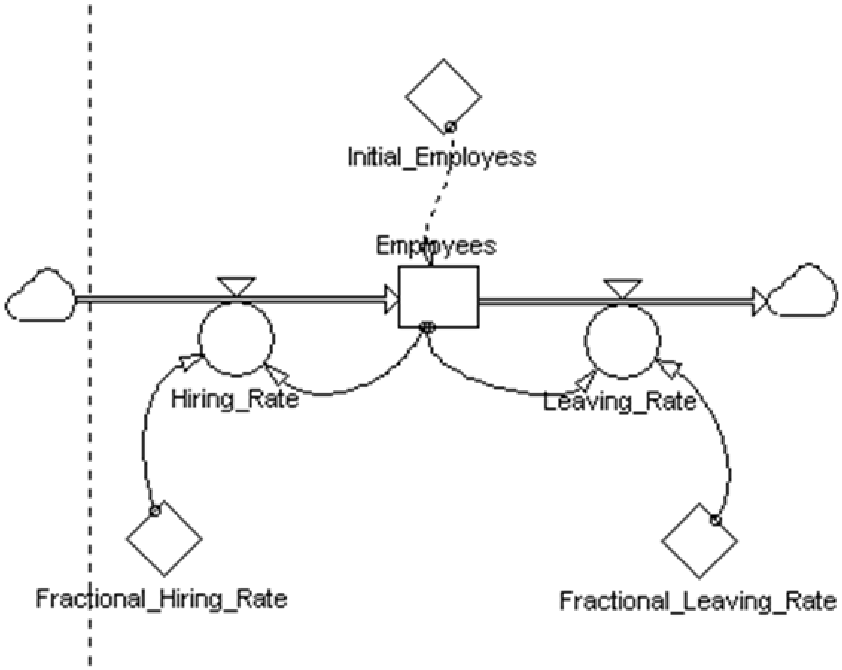
4.2.4.1 Pre-Final Simulation Models

The models were designed to reflect the following main parts of the lesson:

A. Staff components (basic concepts and the basics of Brooks law)
B. Communication channel, work completed and its impact on the work productivity in light of the staff changes and their communication impact
C. Earned Value Management complete scenario

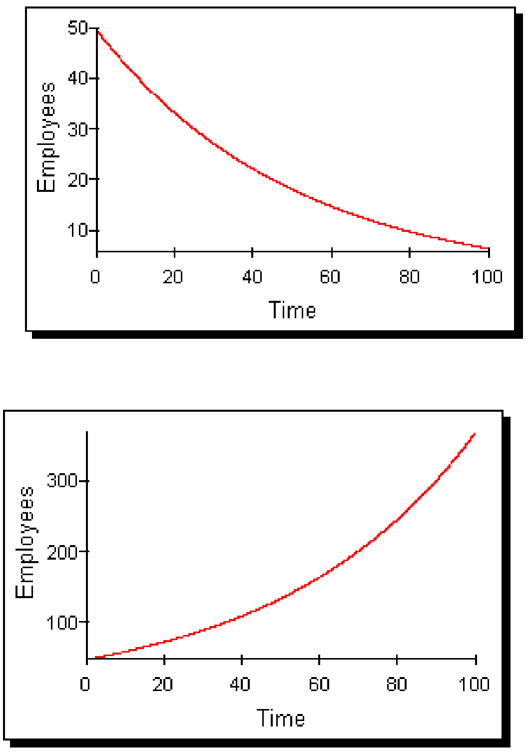
A. Staff components (basic concepts and the basics of Brooks law):

The main SD components have been explained through an analogy to the organisation resources of employees, where employees are representing the 'Stock'. Flows of employees' hiring or leaving increase or decrease the stocks in a gradual way as in (Model I).



Model I

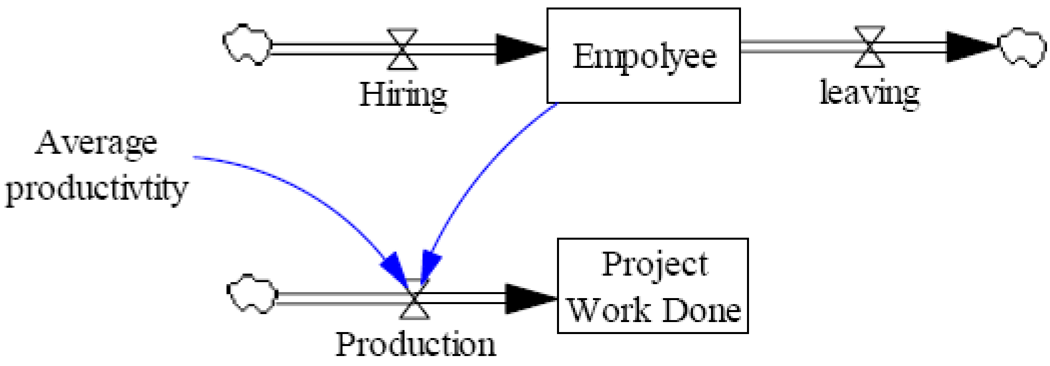
The participants then examined the change of the employees' number over time under different scenarios; i.e. when leaving rate is greater than the hiring one and vice versa as illustrated below 'Model I behaviour'.



Model I Behaviour

B. Communication channel, work completed and its impact on the work productivity in light of the staff changes and their communication impact

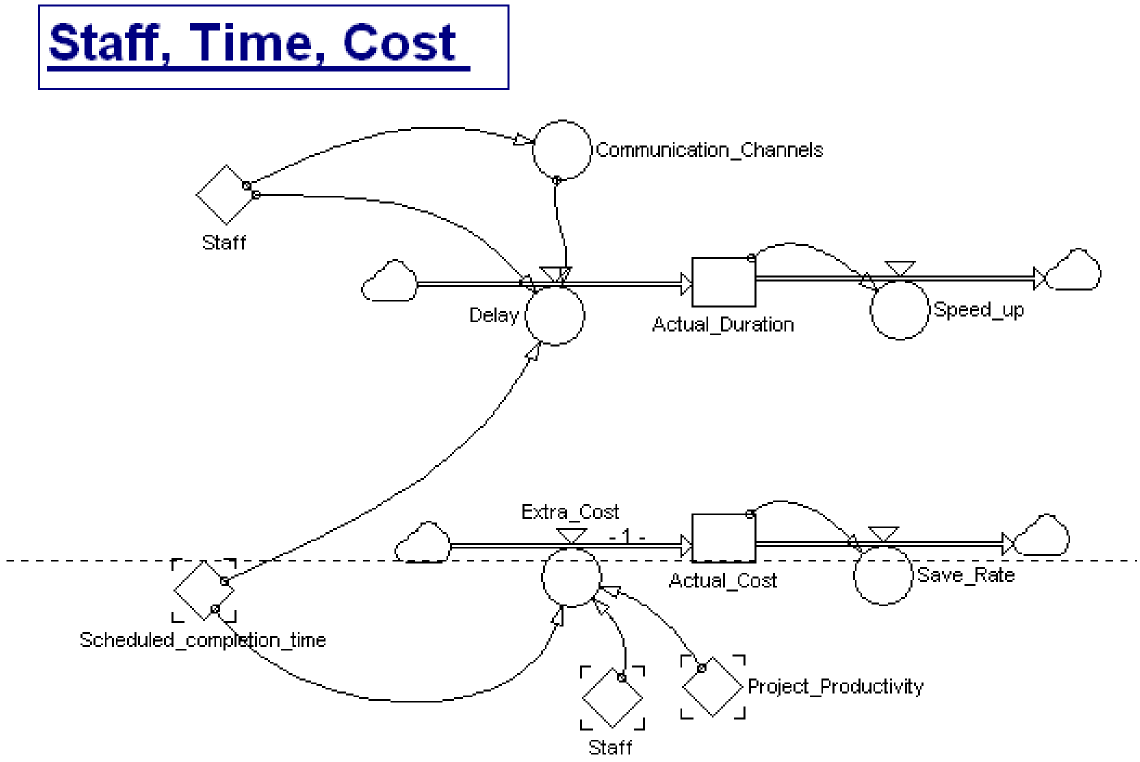
Following the example of the staff hiring, leaving pattern and productivity used by Lizhen, (Lizhen Huang, 2008), participants were given two stock structures related to 'Employees' and 'Project done work'. Besides, information about how Employees constrains the 'rate of production' is indicated textually, as represented in the following 'Model II'.



Model II

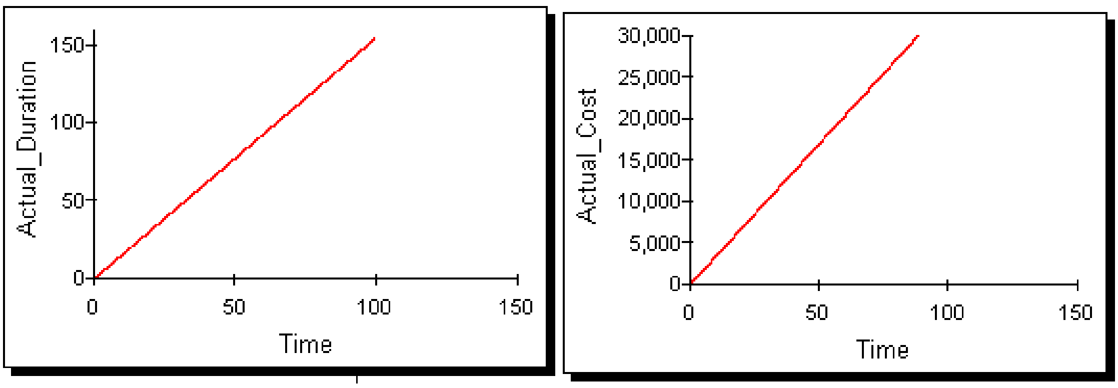
As explained in Appendix 11.A, the participants were allowed to explore the development of the employees and their productivity based on the different hiring rate, and in light of set of given inputs related to the initial number of employees, the different rates of hiring and leaving in different weeks, the initial work done, as well as the productivity rate per employees.

Then the participants moved to a further complicated yet realistic scenario, where they explore a different relation between the employee resources and the productivity, and when the relation could be proportional and reversal at the same time based on different inputs. The staff number, overhead communication between them governed by this equation [(n (n-1))/2], time and cost was introduced. They will explore that adding more staff sometimes increase the productivity, and in other times, adding more staff will lead to more communications overheads, that leads to time increase (more time for the new person to understand the work to be done and the reporting process which results in a delay in the project) which means project delay and different productivity rates (Model III).



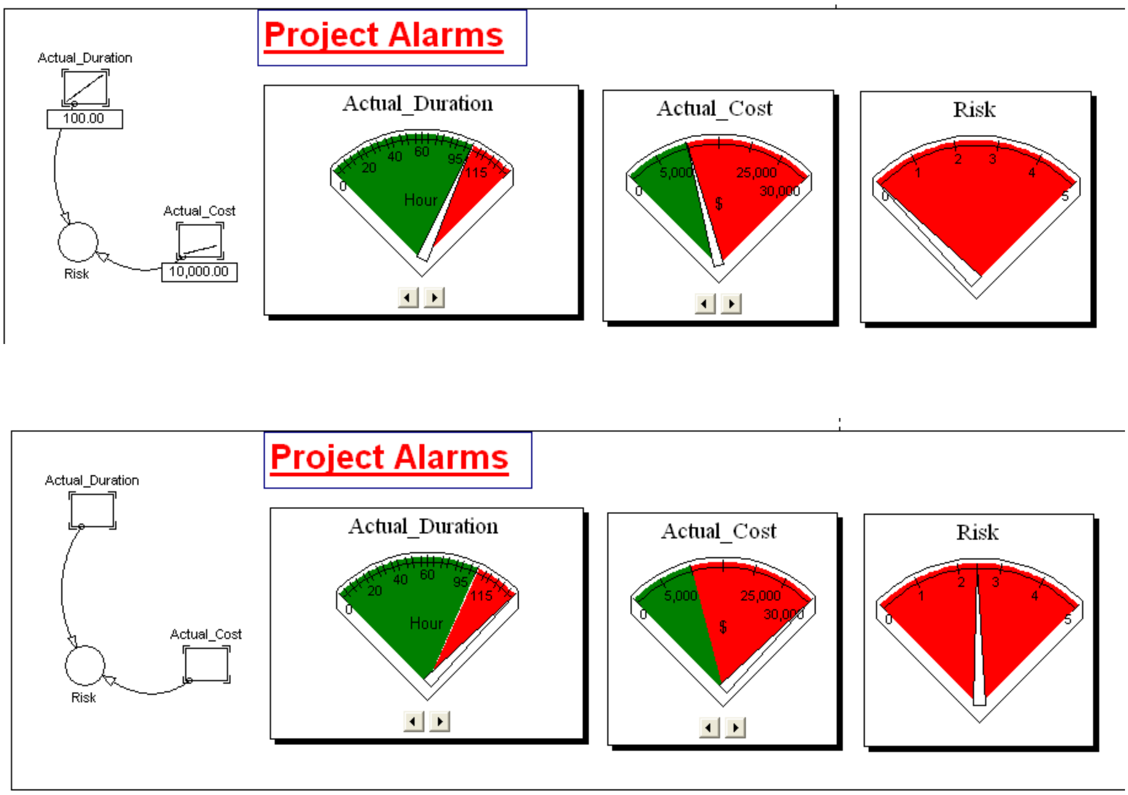
Model III

The model allows the participants to observe the dynamic changes in time and cost per the staff number change as follows in ‘Model III Behaviour’.



Model III Behaviour

The participants also experience when the whole project will be at risk (having both time and cost risk) through the following projects alarms “Model III Alarms”:



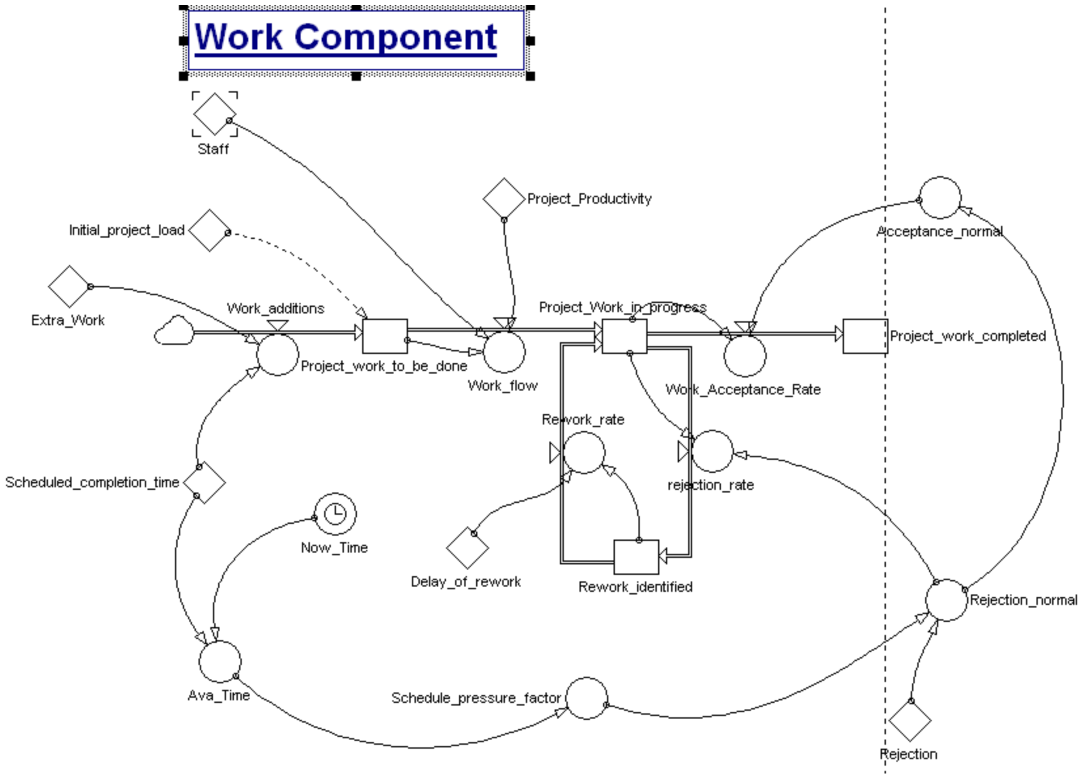
Model III Alarms

This part was explained to the control group participants through an Excel sheet, as explained in Appendix 11.A.

C. Earned Value Management complete scenario

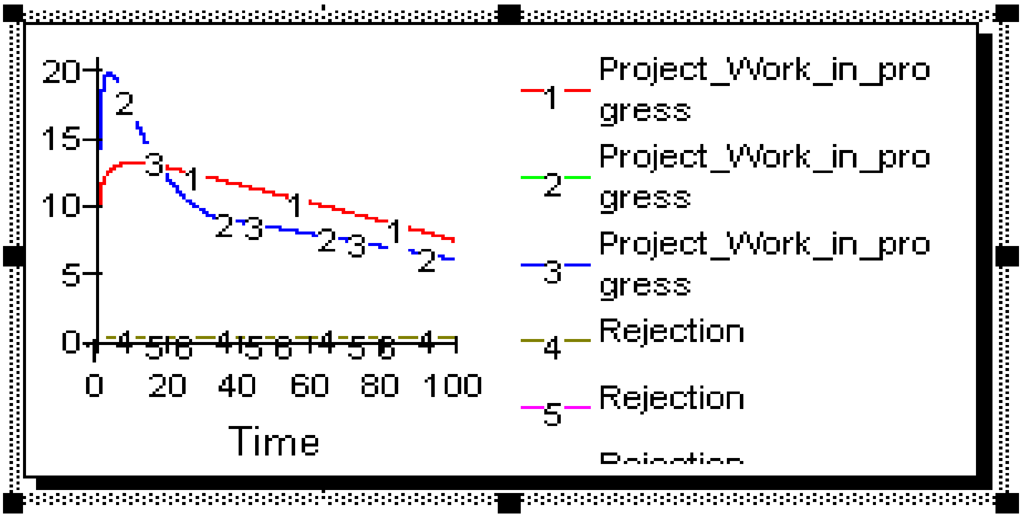
In any project, there is a difference between the planned work to be done, the work in progress, and the actual work completed.

The work in progress is inspected for quality check, which might reveals further rejection rate, followed by identified rework that might affect the project completion as per the planned targets. This new factor has been modelled as follows ‘Model IV’.



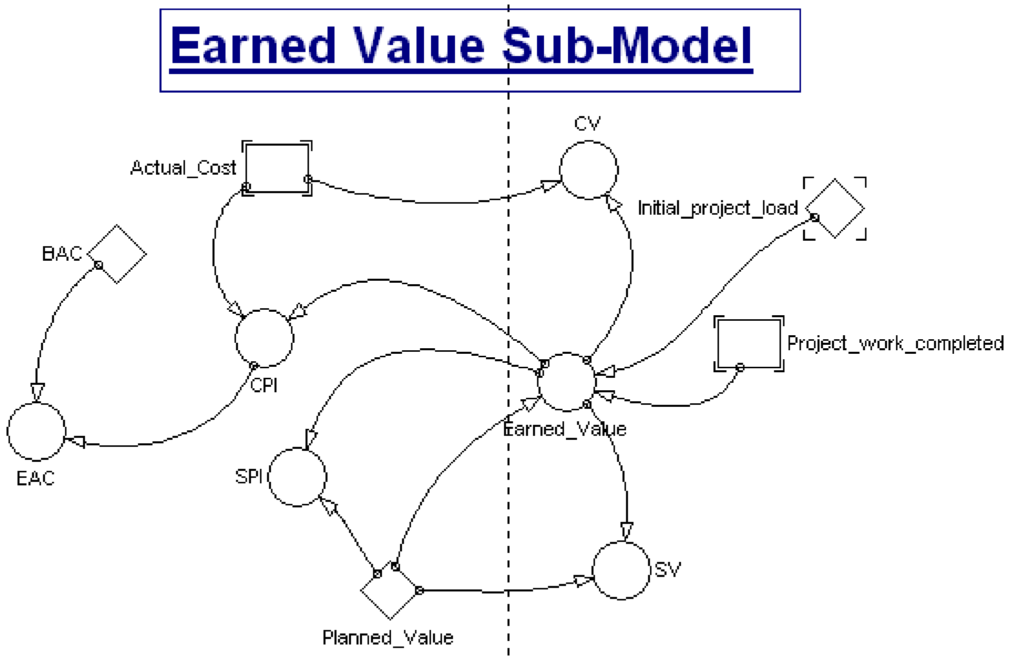
Model IV

The participants explore the behaviour of the work progress with different rejection rates (representing the quality of the work), as in one of the examples 'Model IV Behaviour'



Model IV Behaviour

Then they were introduced to the complete EVM scenario, through the following model 'Model V':



Model V

Then they were asked to explore the EVM changes if they changed different staff numbers and observe its impact on the other indicators.

The complete lesson structure for the experimental and the controlled group is explained in appendix 11.A.

4.2.4.2 Final Simulation Models

Following the structure in Table 2, the final simulation models covered the three main sections in Table 2:

A. EVM Basic Concepts, which is similar for both groups,

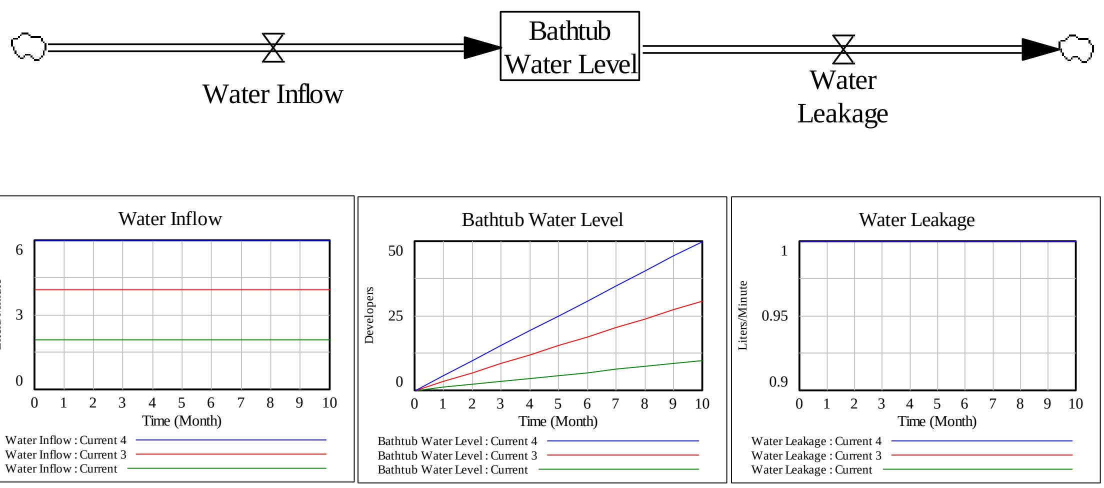
B. EVM applications, which include SD models for the experimental group and similar visualized examples using the Excel spread sheet for the control group, and C. Progressive EVM Examples: that cover direct and complicated examples.

The SD simulations appeared in a gradual way in terms of its complexity and logic sequence of the lesson structure, starting with the first model's concept in step B.2 in Table 2. The following reviewed these models; its instructional details are explained in Appendix 11.B.

A. EVM Basic Concepts:

The basic concepts of stock and flow of SD has been introduced, this has been done through an analogy to a project that targets filling a bath tub with water, with a temporary duration, an estimated budget with a certain return. The tutor goes through a discussion about the different forces that affect the levels of water in the tub: Inflow of water, and the Outflow of water. The learners have been given the bathtub capacity (100 Liters.), and the initial Inflow of (5 Litres/min). Then they go through a discussion about the bathtub behaviour with different filling rates, and when an error happened due to some kind of leakages.

The control group tries this out using Excel spread sheets, and the experiment group went through the following 'Model VI':



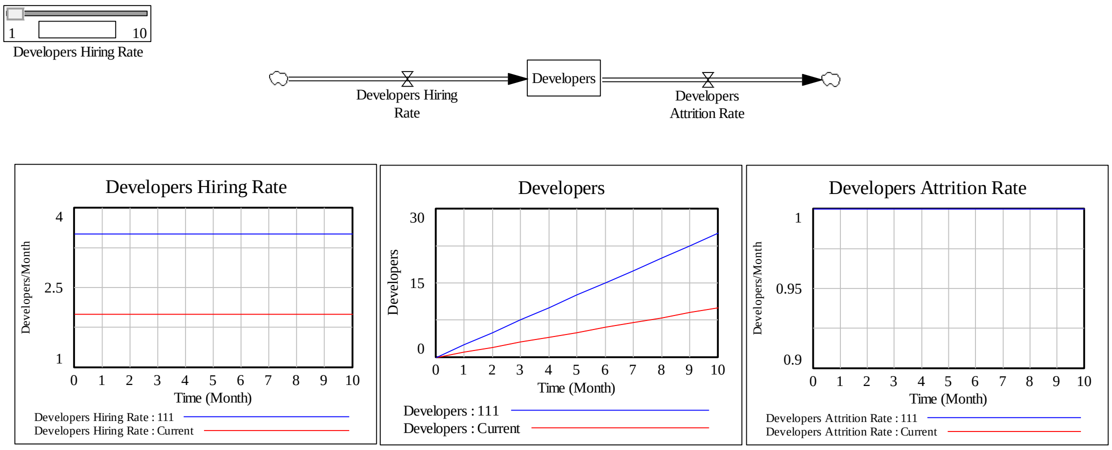
Model VI

A discussion was done with the learners about the cost of filling the bath tub at a specific rate with one litre of water costs us 2 Egyptian Pounds.

Another discussion was done about the needed time and the budgeted cost with different cases of different filling rates and with other different leakage rates, the details of the discussion exist in Appendix 11.B.

B. EVM applications:

An analogy has been made to an enterprise with hiring policy for their employees, moved to a model that includes both of hiring and attrition rates as in the following model 'Model VII'.

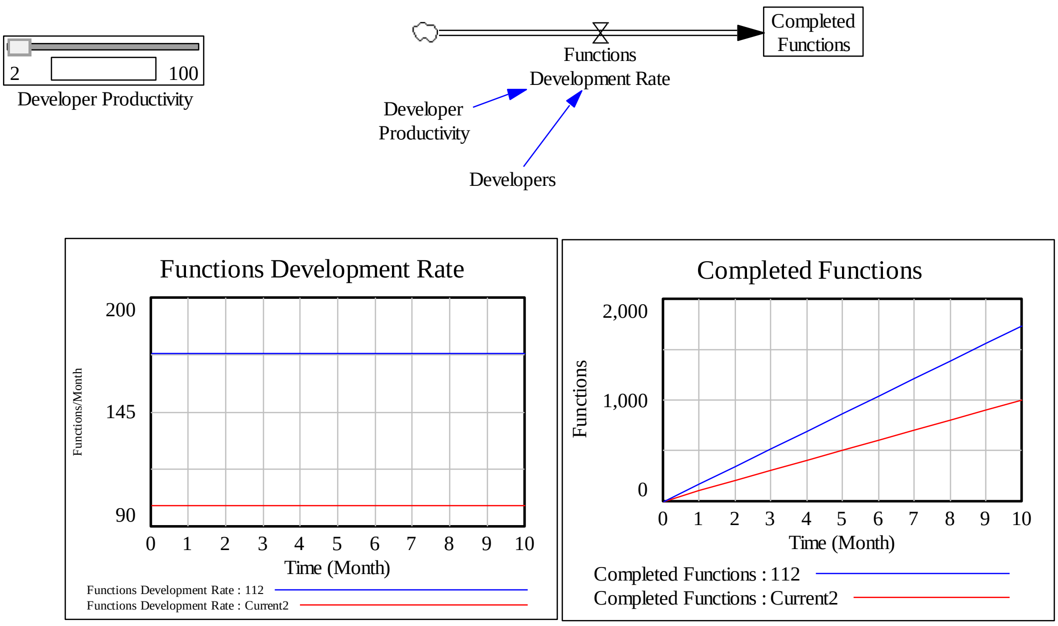


Model VII

Subjects have been engaged in an open discussion about the findings of different variables resulted from the model simulation.

C. Progressive EVM Examples:

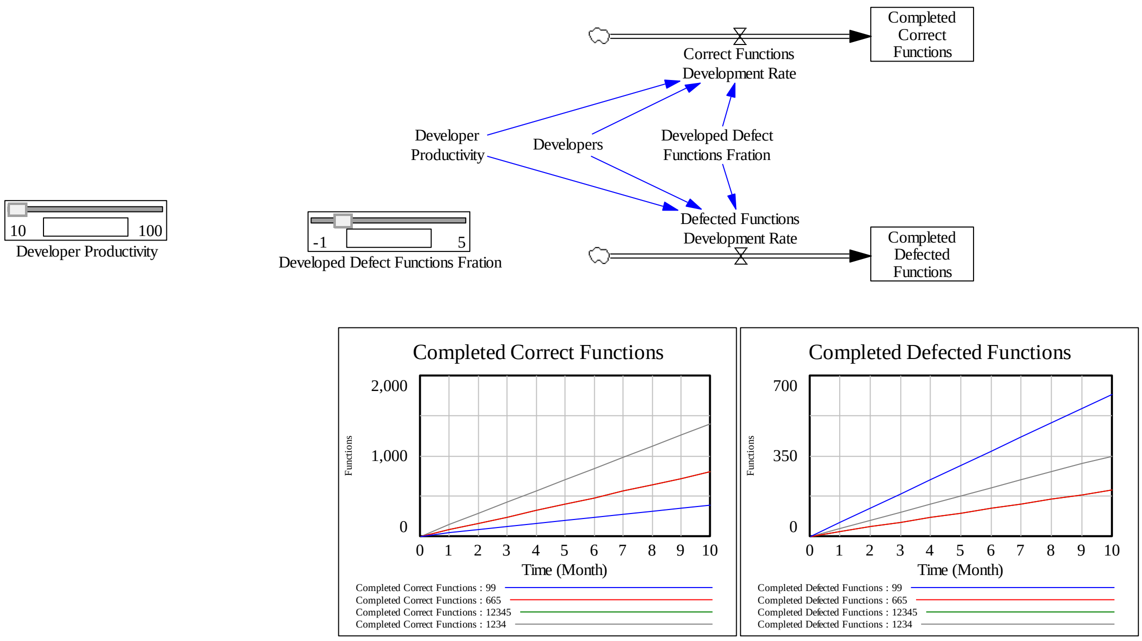
Then another model 'Model VIII' has been developed to take a look over the productivity within a software development company that was defined as a function of the "Number of Developers" and each of the "Developers productivity" (Sometimes calculated as the average productivity of the team).



Model VIII

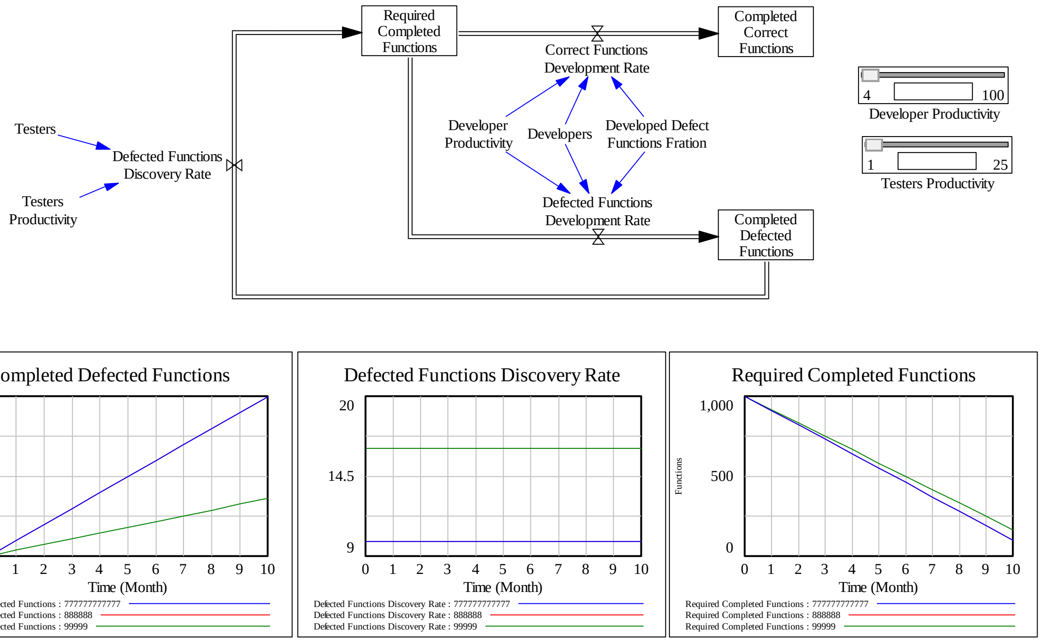
The participants tried out set of scenarios and explored how the system responded as in section of Model III in Appendix 11.B, followed by a discussion on how the number of developers affects productivity and what will happen even if the number of developers is high with lower productivity and the impact on the earned value.

Then, the participants moved into a deeper level at how productivity works in the software development company, being affected by several interconnected parameters, including the number of developers, the productivity of each of them, the number of defected outputs of functions, which entails re-work of the defected units. The above model showed the relation between the productivity of the developers' team and the number of developers on board as well as the amount of defected functions being generated as a by-product of the team's quality drops. There is also a different rate of productivity for the defected functions that is different from the rate of productivity of the new functions being developed 'Model IX'



Model IX

Then they went through set of explorations about different scenarios on the project performance and how that reflects on the different EVM metrics as for example, by setting all the variables at initial levels while setting developers productivity to X instead of Y and run the model, how does that affect project performance as indicated by SPI, CPI and total project time? Other scenarios are listed in the section of (Model X).



Model X

In this model, the participants moved into further complicated situation with a large number of developers and a very effective team that is able to develop functions quickly and re-develop the defected functions. However; the participants here are exploring the scenario of having other variables that could impact the effectiveness of such a powerful team in real life.

4.2.5 Design of the Lesson for the Experimental and Control Group

The lesson plan designed in a progressive way following the main structures below and as explained in the previous Table 2:

- Introduction
- Basic concepts of value and its dynamic nature using the main SD components
- EVM components using progressive example (monitor, explore, analyse, reflect)
- Full scenario, of EVM scenario (apply)

The following table (Table 3) shows the overall structure of the designed lesson for the experimental and controlled group.

Table 3: Lesson Plan for both groups

	Experimental Group	Control Group
Lab Setup	PCs with SD models	PCs with MS Office
Induction	Same Across both groups	
Pre-Test	Same Across both groups	
Lesson Delivery	EVM Basic Concepts: same for both groups	
	EVM Applications Using SD Simulations	EVM Applications Using Paper and XLS
	EVM SD Models-Based	EVM Drill Paper Based
Post-Test	Same for both groups	

4.3 Development of Assessment

4.3.1 Assessment Strategy

There are different types and techniques within the evaluation and the assessment instruments have been included as an important dimension of the qualitative feedback; these techniques were used with the experiment teacher and the participants (Kopainsky Saldarriaga, 2012; Love, 2002) as well as the collected quantitative feedback.

The assessment tool included, three main sections for the pre, during and post-assessment tests with different techniques that included, multiple choice questions, verbal protocols & content analysis, and interviews. Question types in the assessment tool varied between essay questions in which the subject was prompted to write in his/her own words as a way of analysis or explanation of the posed questions. Other questions such as Multiple Choice Questions (MCQs) were introduced to present the subject with different scenarios or solutions from which he/she were to choose from. The following discusses these main three sections of the assessment tool.

4.3.2 The Pre-Assessment Test

The pre-assessment test comes within the screening and filtering mechanism for the experimental study. This screening process ensured that the pool of the trainees from which a random selection was made uniforms with narrow variations in fields of their study and backgrounds. Subjects for the study were selected from a pool of highly homogenous individuals (Already rigorously screened for an advanced Information Technology Diploma through a uniform standardized screening process). The pre-assessment test (As Attached in Appendix 6) is designed to measure the basic understanding of the subjects of the foundation concepts of project management and system thinking skills. Questions were set to measure the early basics of inflow and outflow systems as well as concepts of value and stock levels.

This is the test that has been conducted prior the class to ensure that candidates were allocated in a balanced manner guaranteeing a fair start point that serves the validity of comparing the results.

During the trial of Pilot II, it was important to alternate the pre-assessment, to make sure of the prerequisites of the subjects in terms of their numerical and logical skills. This alteration aims at gauging the participants' ability to perform the mathematical and logical operations that are needed while performing EVM calculations. This was one of the tutor's feedbacks that resulted in extending the time of the pre-assessment; however, this extension was found not needed after Pilot II. Having the participants' faculty background as uniform as possible, in terms of their basic mathematical information, make this extension irrelevant, hence; focusing only on the required skills needed prior the real implementation.

Again, not having this kind of filtration, might include sample of participants who can easily shift the results in different directions just for one reason, not being qualified to join the experiment. So this test is important in making sure of having equivalent entry skills with all the learners.

4.3.3 Reinforcing Activities

The reinforcing activities during the learning process helped the learners to construct their understanding through the experiment. This will help the learners to explore alternative scenarios and enable them to see completely different perspectives based on their own experiential trials and learning. This kind of assessment is more into self-practices that was monitored by the teacher rather than formal questions and exams.

4.3.4 Post Assessment

As described by Forrester and Sterman (Forrester, 1961; Sterman, 2000), the main purpose of SD has always been about learning complex dynamic systems, learning is usually one of the important outcomes. The question is, what does it mean by learning, and how can we assess it. In their work about measuring knowledge acquisition (Kopainsky, et al. 2009), Kopainsky, Alessi, and Davidsen referred to the learning process as the creation or acquisition of new knowledge.

The scope of the current study is about assessing the acquisition of the EVM knowledge within a simulation environment using a system-dynamics-based learning environment. Most of the simulators in general, and SD based environment in specific focus on assessing the participants' performance which is the indication of the "Application" level in Bloom's taxonomy, although this learning skill is important yet it does not reflect the whole picture for the following two reasons:

- The trigger behind this study was not restricted to the learners' scores in the learning environment; on the contrary, their high scores in many times were not related to their level of understanding of the complex system they are studying. So the relation here is not proportional, each separate learning skill should be assessed not in a collective way but in a separate way.
- The challenge of the dynamic complex topics is usually attached to higher levels of learning which is a real challenge for being; rare to assess; difficult to attain through normal instructional way without getting the learners more engaged, and less common.

This is why; the current study will include measurements of knowledge acquisition which is mapped to the various Bloom learning levels (with special focus on knowledge application, analysis). The model set focuses mainly on measuring knowledge and analysis as those are the conventional problems facing Earned Value Management instruction. Trainees usually do not perform well in analysis due to many factors, from which the most prominent is the inability of the traditional instruction method to relate to real life scenario and the interrelation between system components. This deficiency leads to challenges in the areas of Knowledge Acquisition and Analysis.

The post-assessment test (Appendix 7) includes two set of types of questions, one is based on the questionnaire and the other is about feedback and responses that are coming from the trainees and the teacher.

Each of the questions is being mapped to one of the Bloom taxonomy levels. Appendix 7 includes the detailed questions of post-assessment test. Relation between these questions and the learning skills being assessed will be highlighted in the following section.

Post Assessment Question Tagging & Design

Bloom Taxonomy represents a very comprehensive view point of the different cognition levels for a learner (illustrated in the following table: Table 4), so It is quite essential to map the assessment questions to the different Bloom Taxonomy levels. Question Tagging is a way used to identify the types of the questions and to help demonstrating the different areas of assessment being used in the pre / post assessments. Having said that; question tags will significantly improve the ability to analyse the cognition areas in which the participants over/underperformed compared to their peers in the other group (whether Experimental or Control). This way tagging or labelling the questions has been guided by Bloom so that to know what kind of cognitive areas are being assessed or tested.

Table 4: Levels of Bloom's Taxonomy (Bloom, 1956)

Level	Original Domain	New Domain
Level 1	Knowledge	Remembering
Level 2	Comprehension	Understanding
Level 3	Application	Applying
Level 4	Analysis	Analysing
Level 5	Synthesis	Evaluating
Level 6	Evaluation	Creating

As the original and new domains bare great resemblance, the analysis in this study will be based on the original domain of Bloom, for purposes of standardisation and uniformity as shown in the following table (Table 5).

Table 5: Post-Assessment Question Tags

Post Assessment Question Tags – Bloom Based			
No.	Question Number	Primary Bloom Tag	Secondary Bloom Tag
1	Question 1	Comprehension	Knowledge
2	Question 2	Evaluation	Knowledge
3	Question 3	Analysis	Comprehension
4	Question 4	Analysis	Comprehension
5	Question 5	Analysis	Comprehension
6	Question 6	Analysis	Comprehension
7	Question 7	Analysis	Comprehension
8	Question 8	Application	Analysis
9	Question 9	Application	Analysis
10	Question 10	Analysis	Comprehension
11	Question 11	Synthesis	Analysis
12	Question 12	Application	Comprehension
13	Question 13	Application	Comprehension

The above presented table (Table 5) illustrates Bloom Taxonomy's levels represented by each of the post assessment questions, meaning this is the type or kind of Bloom levels that describes this question. Of course, this description has been done following the main Bloom rules and verbs to identify the type of the question. This description aids to understand the weight distribution of the assessment results across the different levels of understanding.

The primary tag - can be called the primary type or kind of question compared to Bloom types of questions - is the primary objective behind posing the question; this means that primarily and essentially this question aims to target that specific area, so for example; if this question tagged as ‘Synthesis’ question, this means the answer to this question indicates the subject's ability/proficiency at that level of ‘synthesis” cognitive level.

The secondary question tag outlines a secondary objective behind asking a question which in most cases and regularly indicates the levels of understanding below the level gauged at the primary tag level. For example Question (5) says "If for a certain given project, the Planned value (PV) is identical to the Earned Value (EV), what does that indicate?" This question mainly measures the subject's ability to analyse this problem and secondarily indicates the subject's ability at the comprehension level.

Although the results’ analysis was done, mapped to the primary tags of questions and not to the secondary one, however; The idea of having primary and secondary tags, has been raised during designing the assessment instrument, so that it helped in maximizing the confidence level of the types of the used questions, when being reviewed to make sure of the addressed areas being assessed. So it could be seen as a further level of checking the types of cognitive levels that are being assessed, which resulted to be similar as illustrated in Fig. 14 and Fig. 15.

The table below (Table 6) shows how many times (primarily and secondarily) each of the knowledge levels tagged or represented was in the post-assessment test (Appendix 7).

Table 6: Post-Assessment Test Tag Breakdown

Level	Original Domain	Primary Tagged	Secondary Tagged
Level 1	Knowledge	0	2
Level 2	Comprehension	1	7
Level 3	Application	3	0
Level 4	Analysis	6	3
Level 5	Synthesis	1	0
Level 6	Evaluation	1	0

By transforming the previous table (Table 6) into a graphical representation, we can clearly see that the post assessment focuses on measuring the different levels up to the "Analysis" level of understanding. This mainly tackles the main challenge point in the selected topic, which is the ability of the subject / student learning Earned Value Management (EVM) to analyse project scenarios and infer relationships between different project components to reach a conclusion.

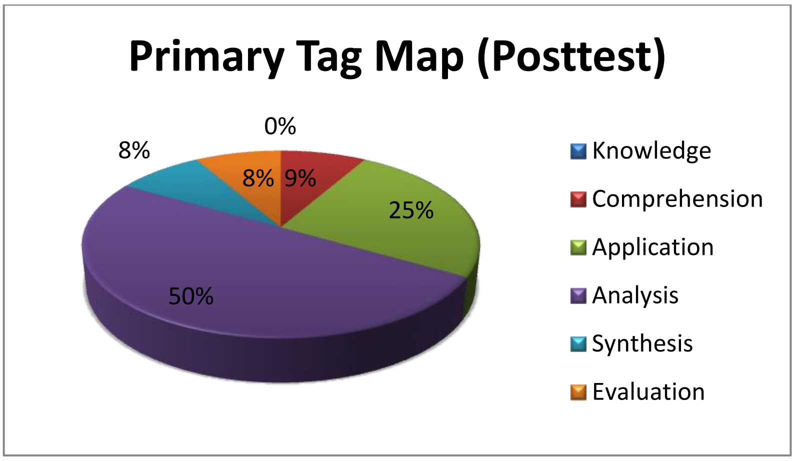


Figure (14): Post-Assessment test Primary Tag Map Distribution

As can be seen from the above Fig. (14), the primary focus of the test design was the measurement of Analysis (50% of the questions were set to primarily measure the ability of the subjects to analyse) and application (25% of the questions were set to primarily measure the ability of the subjects to apply concepts). Hence we can safely say assume that since analysis is pivotally based on all the preceding levels in Bloom's taxonomy; the validity and output of the test measures mainly the subjects' proficiency in Bloom levels 1 through 4 (Knowledge, Comprehension, Application and Analysis). Those four areas are the main areas that were considered problematic at this level of teaching Earned Value Management. The test also measures higher levels of understanding with less focus such as Synthesis and evaluation at 8% concentration each.

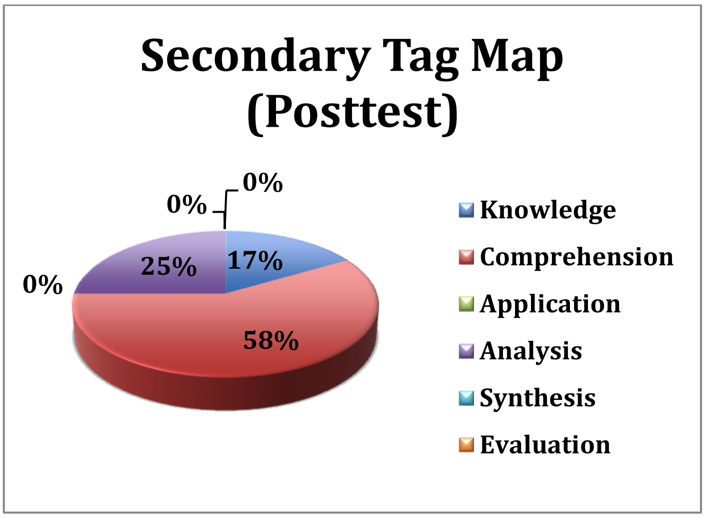


Figure (15): Post-Assessment Test Secondary Tag Map Distribution

Fig. (15) Shows the secondary objectives (Tags) of the post-assessment test questions. As seen in the graph; the most highly evaluated level of understanding is the comprehension level. This makes the most highly evaluated levels of understanding in this assessment are Analysis (primarily) and Comprehension (secondarily). As previously mentioned; the main challenge in the teaching of Earned Value Management is the subject's grasp on the concept and its dimensions (Comprehension) as well as the subject's ability to use the concept comprehension to perform analysis of the problem or case scenarios at hand. The idea of proposing secondary tag, was to identify the question to the nearest type of Bloom levels and accordingly helped in classifying the levels of the question, consequently; creating a sort of a benchmark to cognitive skills of the learners as per these different levels within the assessment tool. Having similar cognitive level distributions as shown in Fig. 14 and Fig. 15 confirmed the targeted cognitive levels of assessment, and considered as a further level of checking the assessed areas.

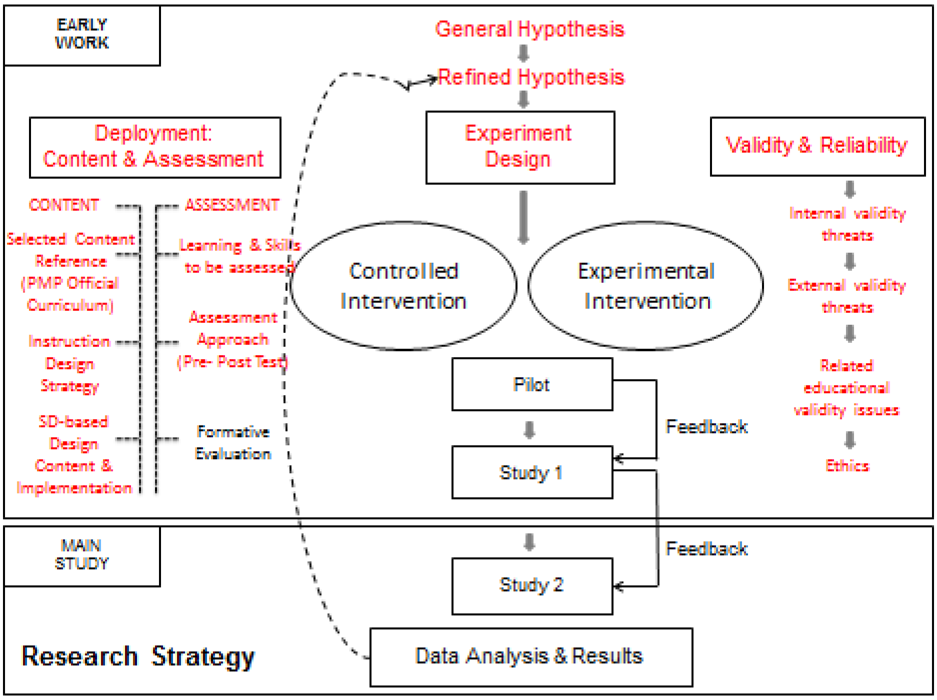


Figure (16): The Fulfilment of the Research Strategy till the Development Processes as covered in the current chapter.

Back again to the main thesis structure described before in Fig (6), now we have covered the design of the experiment as shown in Fig (16), illustrating the progress towards the formative evaluation that will be discussed in the coming chapter.

4.4 Summary

In this chapter, the choice of EVM has been outlined and justified; the rationale of using SD has been briefed, followed by the experiment design for both groups. Chapter (5) will come in the following to present and discuss the formative evaluation of SD simulations and its usage context.

Chapter 5 Formative Evaluation, Pilot and Refinement of Project Management Lesson in Earned Value Management

5.0 Overview

This chapter describes the early formative development and subsequent pilots of the approach to use SD simulations in EVM. For each step procedures, outcomes and formative evaluation goals are reviewed. Also, each step will be related to the mostly affected key formative evaluation goals, and were put to establish (Goal I) the suitability of the content lesson for the experiment, (Goal II) the usability of the System Dynamics simulations and the suitability of the equivalent activity for the control group, (Goal III) the readiness and the appropriateness of the learning context for both groups, and (Goal IV) the overall look of the experiment and testing the hypothesis.

These four goals were referred to in chapter three and explained in more details under section 3.2. as we can see how (Goal II) and (Goal III) are related to the "experiment" itself with respect to both the design of the simulations for both groups, and the fairness of having similar learning context for both groups so that not to be affected by external variables that will affect the causal relation we are assessing. Where we can find (Goal I) is being related to 'the scope of implementation' in terms of the suitability of the idea in general and the content in specific to the used modelling technique, (Goal IV) is mapped to the assessment instrument used to assess the hypothesis. At the end of each phase the changes required to the design of the lessons, the experimental approach and the research instruments are described.

5.1 Initial Validation with Domain Experts

At the commencement of the study, it was important to elicit the views of SD domain experts as to the potential benefits of the proposed investigation into the use of SD in project management education. The two SD specialists consulted, identified here as Expert 1 and Expert 2, held senior positions in academic communities of SD experts in both Egypt and the USA respectively. This step was of a help to realize Goal I, so; an overview of the intended study was forwarded to Expert 1 and Expert 2 with a request for their views on the potential of such an approach for undergraduate students. The feedback from both domain experts was extremely positive and encouraging. Expert 1 felt that the idea was an interesting one, although he felt that it would be challenging in terms of design and assessment and suggested consultation with subject experts. Expert 2 was also very positive, saying:

> "No-one that I know has actually done a study which showed that the integrated curriculum with SD created more and better understanding on the part of students. If you can do that – it would be wonderful". This message doesn't mean that there are no previous studies in this area, but as discussed in details in the chapter of literature review; sections 2.5.1 and 2.5.2, the existing studies that use SD in education are focusing on assessing the learners' understanding of the system thinking skills like feedback, causalities, rather than the topic that encounter these features.

Consequently, it was clear at the outset that the idea to use SD in more mainstream curriculum delivery had significant potential.

Expert 1 & Expert 2 feedback is attached in Appendix 10-A.

5.2 Consultation with Academic and Professional Colleagues

In the next step, a consultation took place with two colleagues from different academic backgrounds to gauge how they might respond to the EVM topic in its traditional form of delivery and to the idea of being taught the topic using a more visual approach using SD simulations within an appropriate learning context (Goal II and Goal III). These participants are identified here as Colleague 1 and Colleague 2; and both were employed at the Information Technology Institute in Cairo.

In a joint meeting, EVM in its traditional format was presented to them on a flip chart. This was followed by a short presentation of SD simulations in EVM using a laptop. Colleague 1, a mechanical engineering Doctor thought that using the simulations was an interesting idea but had reservations about the implementation and the validation. Colleague 2, a political scientist enrolled on an MBA programme, found the EVM topic difficult to grasp in general but thought that dealing with the topic in a more visual way with simulations could be a more help approach (Appendix 10-B).

5.3 Early Pilot – Pilot 1

The goal of the early pilot, entitled (Pilot 1) was to evaluate the appropriateness of the project management lesson in EVM for the experimental and control group and to assess the usability of the SD simulation models. Pilot 1 was conducted with two groups of project management graduates, five attributed to the experimental group and five attributed to the control group.

5.3.1 System Dynamics Simulations of EVM

The System Dynamics simulations were delivered using PowerSim, a simulation tool applying the basic principles and equations of System Dynamics. This was the early available tool at the time.

5.3.2 Participants

These participants had just graduated from the University of Cairo and Ain Shams Computer Science Faculty and had studied project management principles as part of their undergraduate studies. These participants had studied the theoretical basis of EVM, but had not applied or practiced this technique during their undergraduate projects. None of graduates had any previous experience of using System Dynamics simulations.

5.3.3 Procedure

Both the experimental and control lessons were delivered by the researcher at the Information Technology Institute in Cairo and took place in a computer laboratory – an environment with which the graduates were familiar.

- *Experimental Group*

The experimental lesson using System Dynamics simulations of EVM was undertaken first. The System Dynamics simulations on EVM were pre-loaded onto the graduates own lap-top computers and this process took approximately

20 min. The session commenced with a briefing on the study itself and graduates were given a short introduction on EVM using a flip chart and a visualisation of the model using an overhead projector. This introduction to the lesson took approximately 45 min. The participants then accessed the EVM simulations of the 'Developer' problem case using System Dynamics on their own laptops guided by the researcher. The graduates were working through the System Dynamics simulations individually, with the support of the researcher and this part of the lesson took about 30 min. At the end of the lesson the participants were given a post-assessment test which comprised multiple choice questions which assessed their comprehension and application of EVM. This test was paper based.

- *Control Group*

After a 30 min break, the same lesson was conducted with the control group of graduates who had the same introduction to the study but no access to the System Dynamics simulations of EVM 'Developer' problem case and no access at all to computers during the lesson. At the end of the lesson, the participants were given exactly the same post-assessment test conducted in the same manner.

The choice of the type of the experimental learning was done to suit the purpose and the scope of the current study. As discussed in section 3.6, this choice was important to maximize the research validity and the validity of the results.

5.3.4 Outcomes

- *Experimental Group*

During the introductory part of the lesson, the participants were attentive and asked questions about EVM. As soon as the participants started to use the System Dynamics simulations they immediately began to play with the software, trying out the various functions and generally exploring the PowerSim system itself which was new to them. During this unanticipated exploratory activity, the students inadvertently changed some of the features of the simulations, which interrupted the flow of activities. The participants were expecting to apply the EVM equations literally – that is the way that had been demonstrated to them in the lesson as opposed to viewing the relations between the underlying variables and cause and effect governing these relationships. In addition, the participants were very curious about the simulation, about the software technology and how it was being used.

- *Control Group*

As with the experimental group, the control group was attentive during the introductory part of the lesson and asked questions about EVM. The students then tried out the various EVM equations on paper but at that point they were following the equation but had nothing further to engage them.

5.3.5 Result of Post-Assessment Test

The scores of the post-assessment test for the experimental group were better than result for the control group, and were reflected on the research evaluation goals as below.

- *Goal II*

It was clear at the end of the pilot that for both the experimental and control groups, the EVM lesson needed more careful structuring to ensure the gradual introduction of EVM concepts.

- *Goal III*

The participants in the experimental group were very curious about the software and the encompassing models but the System Dynamics models needed to be more incremental – that is there needed to be a more gradual refinement of the design of the full EVM simulation in System Dynamics. In addition, participants were confused by some of the labels given to the stocks and variables in the simulation models so there need to be clearer indicative labels that describe the functions of the various components of the models.

5.3.6 Changes to the Project Management Lesson after Pilot 1

After Pilot 1, the basic structure of the project management lesson in EVM stayed broadly the same, but there was more refinement to the System Dynamics simulations (Goal II) which included better gradualism and labelling of variables. To give the control group equal experience in terms of technology usage, Excel spread-sheets and graphs were developed to provide visualisations on a computer that were previously shown to control group's students on flip charts and the overhead projector (Goal III).

5.4 Consultation with Project Management Practitioner and System Dynamics Professional

Going into a second pilot, it was important to conduct a final appraisal of the project management lesson content and structure in terms of the material to be delivered in both the experimental and control groups, and the SD simulations in EVM to be used with the experimental group. The lesson content for both groups was reviewed by a Certified Project Management Practitioner, here identified as PMP 1 and by a System Dynamics Practitioner, here identified as SDP.

PMP 1 confirmed the difficulty of EVM as a topic (Goal I), affirmed the incremental approach to the delivery of the SD simulations in EVM and the changes to the variable labelling and checked the lesson content including the material delivered in simulations and spread-sheets for the experimental and control groups respectively (Goal II & Goal III) and proposed not to adapt the questions too much in a way serve the system approach, but rather to make it more topic based. (SDP) who was supportive of the approach checked the SD simulations in EVM and assured the effectiveness of the models (Goal II) (Appendix 10-C).

5.5 Second Pilot – Pilot 2.

The goal of the second pilot, entitled Pilot 2. was to evaluate the refined learning context for both the experimental and control groups and to assess the changes made to the SD simulation models of EVM in preparation for the final study. It was also an important goal of Pilot 2 to evaluate the pre-assessment test and post-assessment test research instruments. The second pilot entitled Pilot 2. was conducted with two groups of 15 graduates in each of the experimental and the controlled group.

5.5.1 System Dynamics Simulations of EVM

The used System Dynamics simulations software in this stage was ‘VenSim’ software. Like ‘PowerSim’ software, this software is a simulation tool applying the basic principles and equations of System Dynamics. However, it provides a more flexible and easier way for developer to upload the simulations and for the user to get access to free and available versions.

5.5.2 Participants

The participants in Pilot 2 were graduated from the University of Alexandria and as with the graduates in Pilot 1 had studied project management principles as part of their undergraduate studies. These participants had studied the theoretical basis of EVM, but had not applied or practiced this technique during their undergraduate projects. None of graduates had any previous experience of using System Dynamics simulations.

5.5.3 Procedure

Having verified the overarching lesson structure and research protocol in Pilot 1, it was important to eliminate any possible bias that might be introduced by having the researcher deliver the lessons to the experimental and control groups in any further implementation studies. Consequently, in Pilot 2, both the experimental and control lessons were delivered by an independent tutor at the

Information Technology Institute in Cairo, that is – a tutor other than the researcher. Both the experimental and control lessons took place in the same computer laboratory but in Pilot 2, the VemSim software and SD simulation models of EVM were loaded in advance.

5.5.4 Outcomes

- *Experimental Group*

During the introductory part of the lesson, the participants were attentive and asked questions about EVM. More fined control was on the flow of the session, the participants were interested to gradually explore the different models – In addition, the participants were very curious about the simulation, about the software technology and how it was being used.

Sometimes, most of them were trying to relate between what the theory part they went through in the beginning of the experiment and the practices they are trying with the models. However, it was planned during the session, to raise this question by the tutor himself and open the floor for the discussion.

- *Control Group*

As with the experimental group, the control group was attentive during the introductory part of the lesson and asked questions about EVM. The students were attracted to the idea of seeing the spread-sheet; few of them looked for a simulation program that could visualize these relations, One might ask, why would the participants ask for this in the first place, the answer might be related to their study background, those students are coming from an engineering background with more acquaintance and awareness with different programming and simulation techniques, and their work with the Excel spread-sheet and the changes happened over it, triggers their programming background and skills to ask if there is more advanced visualized tool like simulation to do the same function.

5.5.5 Results of Post-Assessment test

- *Goal I*

It was clear at the end of the second pilot that for both the experimental and control groups, the EVM lesson structure was now more effective, engaged both study groups and gave participants a roughly equivalent experience using computers in the learning environment.

- *Goal II*

The participants in the experimental group found the increased incremental nature of the SD simulations of EVM easier to follow and were consequently more engaged in the task. In addition, participants found the revised labelling of variables easier to understand.

- *Goal III Research Instruments*

Having the tutor and his fresh looking over the whole stuff this time affected the sharp timing handle during the experiment, as well as amending the assessment instrument. After the Pilot I, the pre-assessment has been shortening to be 30 min instead of 45 min. prior this pilot, the tutor suggested including set of skills in the post assessment questionnaire to assess the comprehension and the analysis of the experiment and shortening the pre-assessment exam and trim this part related to assessing the subjects' numerical and logical abilities (Tutor Feedback in Appendix 10-D) Also, the tutor suggested to update the questions and make it not directly related to a sub-chunk or directly to be system based questions rather than project management related as clear from the (Appendix 11.B: Early Phases Lesson Plan).

5.5.6 Changes to the Project Management Lesson after Pilot 2

After Pilot 2, the basic structure of the project management lesson in EVM stayed broadly the same, but there was more refinement to the System Dynamics simulations (Goal I) and to give the control group a more balanced experience in terms of technology usage, Excel spreadsheets and graphs were developed to provide visualisations on a computer that were previously shown to students on flip charts and the overhead projector (Goal II).

The final lesson structure for the experimental and control groups following refinements in Pilot 1 and Pilot 2 is outlined in Table 7 below, and their details are attached in Appendix 11.A and Appendix 11.B.

Table 7. Final Lesson Structure for Experimental and Control Groups

No.	Item	Duration	Description
Total Duration per each group is: (around 4 Hrs)			
1	Induction	5 Minutes	**Control & Experimental Group:** An orientation to the experimental study and its objectives.
2	Pre-test	30 Minutes	**Control & Experimental Group:** Administration of the pre-test used to ensure there is no variation in the subjects' levels across the two groups
3	Concept Training	2 Hours	**Control Group:** Instruction of the basic value and EVM concepts using PowerPoint presentations as well as MS Excel as a calculation aiding tool for the subjects. **Experimental Group:** Training on the basic value and EVM concepts using PowerPoint presentations and simulations using SD tools (VenSim)
4	Post-test	1.5 Hour	**Control & Experimental Group:** Administration of the post-test to measure the learning progress

			across the two groups

Having now described the formative design stages and its reflective on the main study, the red colour in the following Fig (17) illustrates progress towards the fulfilment of this stage inside the overall research study.

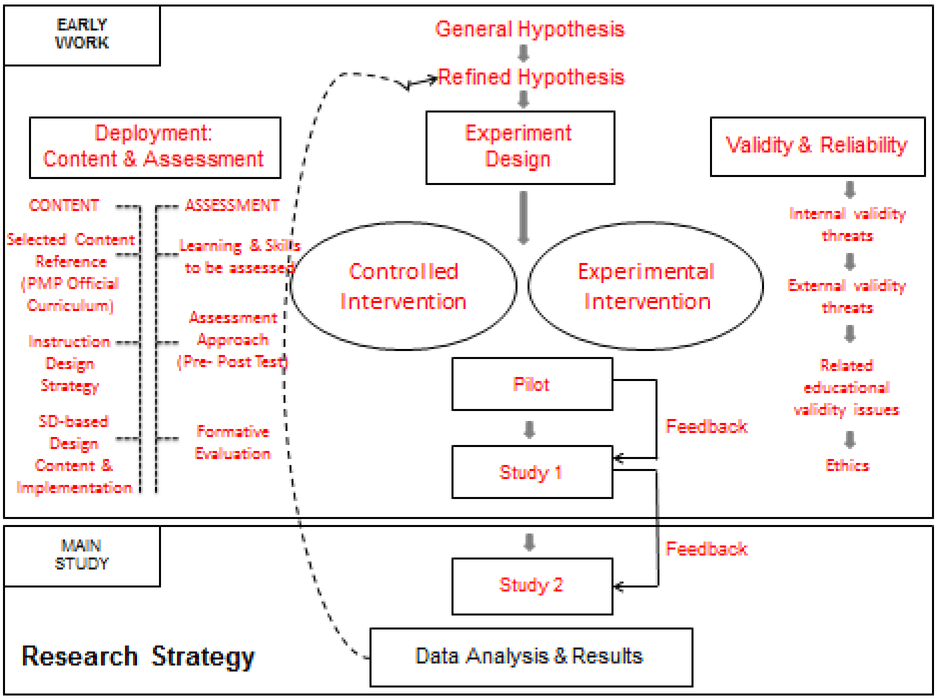


Figure (17) Fulfilment of Research Strategy up to the Data Analysis and Results

5.6 Overview of Formative Evaluation and Refine Steps of the Project Management Lesson and Experimental Protocol

The following (Table 8) summarizes the formative evaluation of the experimental and control group lessons and the research protocol.

Table 8: The Formative Evaluation of the Experiment

Formative Step	Participants	Intended Goals	Feedback &/Insights	Actions
Idea Validation with Domain Experts	Expert 1 Expert 2	Goal I	**Interesting** yet challenging in term of realization; advise engaging subject expert **Positive** feedback regarding seeing on the ground the results of SD learning based impact	Further reading and reviewing others' work and challenges
Consultation with Academic and Professional Colleagues	Colleague I Colleague II	Goal II Goal III	**Colleague I: Interested** yet with inquiries about the way to implement and assess **Colleague II: Interesting** Visualization tool, yet having difficulty to get the topic with either approaches	Prepare for the first Pilot study identified here as Pilot I

First Pilot - Pilot I	5 participants / each group	Goal II Goal III Goal IV	Experimental pilot group score relatively higher	**Amend** the lesson material and the used models to be more gradual and informative **Get** neutral tutor rather than the researcher **Amend** the research instrument
Consultation with PM Practitioner and SD Professional	PMP 1 SDP	Goal II	**PMP 1** reviewed the lessons and was curious about the results **SDP** reviewed the idea and validated the simulation models, was interested and biased specially one of them	Lesson material ready for Pilot II
Second Pilot – Pilot 2	15 participants / each group & New Tutor	Goal II Goal III Goal IV	Tutor reviewed the testing instrument	Final lesson plan and research instrument were ready for the final experiment

Goal I: The Content Suitability **Goal II:** Usability **Goal III:** Learning Context **Goal IV:** Hypothesis Test

Table 8 summarized the different development phases and steps of the experiment, starting from the idea and how it was validated, and refined with different academic and professional experts in the field, to the different pilots of implementation. The table also summarized the different participants in each of these steps, and what is the relation between each of these steps and the mostly affected evaluation goal. Finally, the table showed, the taken actions and changes that was considered or implemented after each of the different steps.

5.7 Conclusion

By the end of the formative design and development stage all lesson materials and research instruments were in place to undertake the final study. Full details of the final study with quantitative and qualitative results and analysis are reviewed in Chapter (6).

Chapter 6 Research Study

6.0 Goals of the Main Research Study

The goal of the main study was to examine the research hypothesis which proposed that simulation based learning, in this case SD is the simulation technique that was selected for the study, when used with a specific set of topics, in this case Earned Value Management as a part of PM, could lead to improved understanding of complex management situations and higher achievement scores in post-assessment tests.

The full SD simulation models developed to test this hypothesis are provided on (Appendix 12).

This chapter will present the results of the methodology outlined and Chapter (3) and implemented in Chapter (4) and (5). The results of this study will help assessing whether SD based learning is effective or not in light of the qualitative and quantitative analysis of the post assessment scores and answers.

The quantitative analysis will be done for the overall results in terms of the scores, as well as the words and the characters numbers for the controlled and the experiment groups.

The analysis will also address the inconclusive quantitative analysis through which there was no either significant or zero difference in the scores of both groups in their post assessment questions.

The analysis will address also in details the overall qualitative analysis, followed by detailed qualitative question for each of the non-MCQ question.

Also, in light of this analysis, and in light of the overall developmental phases of the experiences, a set of guidelines will be provided on further development of SD learning based applications in the area of project management that will help other researchers, and educators.

6.1 Procedure

Project management training on Earned Value Management was made available to two groups of project management students, the first in a traditional format to a control group and the second deploying SD simulations based learning to an experimental group. Using questions mapped to Bloom's Taxonomy, both quantitative and qualitative data were collected in order to test the hypothesis.

6.1.1 Research Protocol

The research procedure followed that described in Section 3.1.3 and operationally implemented in the pilot study 1 and 2. The changes from the pilots were that adjustments were made to include the usage of a computer by participants in both groups, and to engage an external instructor rather than the researcher, with the aim of minimizing any affecting variables on the experiment validity.

6.1.2 Participants

Forty six participants took part in the last full implementation of the experiment and twenty three participants were assigned randomly to each group. All the participants completed the entire experiment including the pre and post-assessment tests. Participants from the control will be referred to as Control Std.1 to Control Std. 23 respectively and participants from the Experimental group will be referred to as Experimental Std.1 to Experimental Std. 23 respectively.

All participants were postgraduates from University of Assiut, Faculties of Engineering, Computer Science and Commerce with almost an equal split of distribution, see Table 9 below.

Table 9: Participants' Background

Faculty	Experimental Group	Control Group
Engineering	11	10

Computer Science	11	11
Commerce	1	2
Total No of Participants	23	23

It is worth noting that 80% of the participants were females and 20% males reflecting the Egyptian gender distribution across these faculties in this particular academic year; however the gender ratio was carefully controlled across the experimental and control groups. All participants were in their early twenties. A summary of all participants who completed the experiment is provided in Table 10 and Table 11 below.

Full details of the data collected from the screening questionnaires for the whole set of forty six participants is available in Appendix 13 and Appendix 14. The total length of time that participants took to complete the experiment was 3 hours and 35 min including: a pre-assessment test (30 min), instructions (2 hr), post-assessment test (1.5hr).

Table 10: Summary of Participants – Experimental Group

ID	Faculty	Gender
Experimental Std.1	Engineering	F
Experimental Std.2	Engineering	F
Experimental Std.3	Engineering	M
Experimental Std.4	Engineering	F
Experimental Std.5	Computer Science	M
Experimental Std.6	Computer Science	F
Experimental Std.7	Commerce	M
Experimental Std.8	Engineering	F
Experimental Std.9	Computer Science	F
Experimental Std.10	Engineering	F
Experimental Std.11	Engineering	F
Experimental Std.12	Computer Science	F
Experimental Std.13	Engineering	F

ID	Faculty	Gender
Experimental Std.14	Computer Science	F
Experimental Std.15	Computer Science	M
Experimental Std.16	Computer Science	F
Experimental Std.17	Computer Science	F
Experimental Std.18	Engineering	F
Experimental Std.19	Engineering	F
Experimental Std.20	Computer Science	M
Experimental Std.21	Engineering	F
Experimental Std.22	Computer Science	F
Experimental Std.23	Computer Science	F

Table 11: Summary of Participants – Control Group

ID	Faculty	Gender
Control Std.1	Computer Science	F
Control Std.2	Commerce	F
Control Std.3	Computer Science	F
Control Std.4	Commerce	F
Control Std.5	Engineering	F
Control Std.6	Computer Science	F
Control Std.7	Computer Science	F
Control Std.8	Engineering	F
Control Std.9	Computer Science	F
Control Std.10	Engineering	F
Control Std.11	Computer Science	M
Control Std.12	Computer Science	F
Control Std.13	Engineering	F
Control Std.14	Computer Science	F
Control Std.15	Computer Science	F
Control Std.16	Engineering	F
Control Std.17	Computer Science	F
Control Std.18	Engineering	F

Control Std.19	Commerce	M
Control Std.20	Engineering	F
Control Std.21	Engineering	F
Control Std.22	Engineering	M
Control Std.23	Computer Science	M

6.2 Results

In the following sections, the results of the study including positive and negative or inconclusive quantitative and qualitative results of the post-assessment test undertaken by the experimental and control groups respectively will be presented.

The post-assessment test included 13 questions. Question 12 was a four part question and question 13 was a seven part question. Each question or part question scored one point; consequently a maximum of 22 marks could be achieved by a participant in the each test. Questions 1, 2, 8 and 9 were Multiple Choice Questions (MCQ) where participants were asked to choose the correct answer from a series of five distractors; however in the majority of questions participants were required to write solutions to problems, including the use of mathematical equations, providing their own explanation as to how they had come to the solution.

Excluding those questions that used an MCQ test format, participants were expected to write their answers and this included explanations of how participants solved the problems set in the test. Consequently as well as demonstrating a correct answer, participants written explanations provide further evidence of how they came to answer the question, and this qualitative data will be used to triangulate the results of the quantitative analysis.

6.2.1 Quantitative Evidence for the Impact of SD on Participants Learning of EVM

6.2.1.1 Comparison of Overall Results

An independent groups T-test was conducted to compare scores for the total numbers of questions answered correctly by the experimental and control groups and to establish whether or not there was a significant experimental effect. The results in Table 12 shows that the scores for the experimental group were significantly greater than that of the control group (t=4.601, df=44, p<0.0005).

Table 12: Comparison of Overall Results for Experimental and Control Group

	Participant Group	N	Mean	Std. Dev
Number of Correct Answers	Experimental Group	23	13.2609	2.63227
	Control Group	23	9.3913	3.05613

6.2.1.2 Comparison of Questions Assessing Problem Analysis Using EVM

In the post-assessment test, questions 3-7 and question 10 were designed to assess participants' problem analysis. For the experimental and control group participants, the results for these questions were aggregated and an independent groups T-test conducted to compare scores for the numbers of questions answered correctly and to establish whether or not there was an experimental effect. The results in Table 13 shows that the scores for the experimental group were significantly greater than that of the control group (t=2.835, df 44, p=.007).

Table 13: Comparison of Overall Results for Experimental and Control Groups for Problem Analysis

	Participant Group	N	Mean	Std. Dev
Number of Correct Answers	Experimental Group	23	4.6087	.99807
	Control Group	23	3.6087	1.37309

6.2.1.3 Comparison of Questions Assessing Knowledge Application Using EVM

In the post-assessment test, questions 8, 9, 12 (parts a,b,c,d) and 13 (parts a,b,c,d,e,f,g) were designed to assess participants knowledge application. For the experimental and control group participants, the results for these questions were aggregated and an independent groups T-test conducted to compare scores for the numbers of questions answered correctly and to establish whether or not there was an experimental effect. The results in Table 14 shows that the scores for the experimental group were significantly greater than that of the control group (t=4.165, df 44, p<0.0005).

Table 14: Comparison of Overall Results for Experimental and Control Group for Knowledge Application Using EVM

	Participant Group	N	Mean	Std. Dev
Number of Correct Answers	Experimental Group	23	6.6957	2.22455
	Control Group	23	3.8261	2.44303

6.2.2 Inconclusive Quantitative Results for the Impact of SD on Participants Learning of EVM

In the post-assessment test, questions 1, 2 and 11 were designed to assess participants' comprehension, evaluation and synthesis of EVM respectively. As only one question in the post- assessment test was used in each case, a Pearson Chi-Squared test was conducted to compare these single scores and to establish whether or not there was an experimental effect.

6.2.2.1 Comparison of Question 1. Assessing Comprehension of EVM

A Pearson Chi-Squared test was conducted to compare scores for Question 1. for the experimental and control groups and to establish whether or not there was a significant experimental effect. The results show that there was no significant difference between the experimental and control groups (x2=.518, df=1, p=.472) for participants scores for this question.

6.2.2.2 Comparison of Question 2. Assessing Evaluation of EVM

A Pearson Chi-Squared test was conducted to compare scores for Question 2. for the experimental and control groups and to establish whether or not there was a significant experimental effect. The results show that there was no significant difference between the experimental and control groups (x2=.226, df=1, p=.635) for participants scores for this question.

6.2.2.3 Comparison of Question 11. Assessing Synthesis of EVM

A Pearson Chi-Squared test was conducted to compare scores for Question 11. for the experimental and control groups and to establish whether or not there was a significant experimental effect. The results show that there was no significant difference between the experimental and control groups (x2= 099, df=1, p=.753) for participants scores for this question.

This level of insignificance difference is quite clear in terms of the total number of correct answers for experimental group (8 correct answers), versus the number of correct answer in the control group (7 correct answers). However; I would refer this insignificant difference to the fact of applying this level of assessment almost the last experimented part in the SD based lesson, which was not being practiced well. Hence; didn’t reveal deep difference with the results.

Further guidelines regarding this delivery issue will be discussed later on in the upcoming chapters.

6.2.2.4 Summary of Post-Assessment Test Positive and Inconclusive Quantitative Results

The overall comparison of results showed a highly significant difference between the experimental and control groups, with the experimental group having significantly greater scores. This comparison was based upon a total possible score of twenty-two points in the post- assessment test.

The design of the post- assessment test focused predominantly upon the assessment of the categories of Application and Analysis as outlined in Bloom's Taxonomy. Participants were assessed on Application and Analysis with the potential to achieve total scores of 13 and 6 respectively, taking into account that Question 12 had four parts and question 13, seven parts. For both Application and Analysis, results for the experimental group were also significantly better than the control group, and for Application this result was highly significant. It is clear that the more available questions to aggregate for a particular category of Bloom's Taxonomy, the more significant the effect.

Where only one question was used to assess performance against a specific category of Bloom's Taxonomy, no significant difference was demonstrated.

Table 15: Summary of Post-Assessment Test Positive and Inconclusive Quantitative Results

Category of Blooms Taxonomy	Questions	Statistical Test	Significant Result*	Independent Samples Test
All	1-13	Independent Groups T-test	$p<0.0005^{*}$	Sig. [2-tailed]
Comprehension	1	Pearson Chi-Square test	p=.472	Asymp. Sig. [2-sided]
Application	8, 9, 12, 13	Independent Groups T-test	$p<0.0005^{*}$	Sig. [2-tailed]
Evaluation	2	Pearson Chi-Square test	p=.635	Asymp. Sig. [2-sided]
Analysis	3-7, 10	Independent Groups T-test	$p=.007^{*}$	Sig. [2-tailed]

Synthesis	11	Pearson Chi-Square test	p=.472	Asymp. Sig. [2-sided]

6.2.3 Qualitative Evidence for the Impact of SD on Participants Learning of EVM

Qualitative data consisted of written responses to questions in the post-assessment test that is to questions 3-7 and 10 to 13; questions 1, 2, 8 and 9 were in an MCQ test format. In addition questions 12 and 13 were multi-part questions with four and seven parts respectively. The written responses included formulas, and written explanations as to how participants had solved the problems set in the post- assessment test. Unlike those questions that used an MCQ test format, written answers collected during test conditions provide credible evidence of the knowledge resources that participants used to answer those questions in the test that required a written solution.

6.2.3.1 Qualitative Evidence for the Impact of SD on Participants Learning of EVM through Access to Knowledge Resources

To make the most straightforward comparison of participants access to the knowledge resources they needed to answer the post- assessment test questions, a comparison was made between the number of characters and words that were written by the experimental and control groups, firstly for all the written format questions in the test, then subsequently for written questions grouped according to the categories of Bloom’s Taxonomy. A summary of this qualitative data is provided in the table 16 below.

Table 16: Knowledge resources – Comparison of Experimental and Control Groups

Category of Bloom’s Taxonomy	Number of characters		Number of words	
	Exp.	Control	Exp.	Control
All questions	16,863	11,341	3,608	2,614
Analysis	11,214	6,867	2,594	1,620

Q3, Q4, Q5, Q6, Q7 and Q10				
Synthesis Q11	1,119	1,096	254	263
Application Q12a-d & Q13a-g	4,530	3,378	760	731

Note: This section is about qualitatively analyzing the participants' answers that were allowing for further explanations by the participants, For Q1 & Q2, these are MCQ questions; their results wouldn't add to this kind of analysis, so their results are not considered in this section.

From the table above (Table 16) looking at a comparison for all questions, it is clear that as whole participants in the experimental group have written much more during the post- assessment test than participants in the control group. It is important to note that these summations of qualitative data include written formulas as well as words and that the summation of all qualitative data for written questions includes those answers that were incorrect, as well as correct. However, looking at the data as a whole, and recognizing that the quantitative results outlined above demonstrated a significant difference between the experimental and control groups performance in the post- assessment test, it is reasonable to conclude that in general participants who had learned EVM using SD simulations appeared to have more knowledge resources with which to respond to the questions set in the test; this qualitative result provides a credible triangulation of the quantitative results outlined above.

Clearly during the post- assessment test, both the experimental group and control group would be drawing from their previous knowledge of project management, plus knowledge of EVM delivered with or without SD simulations, to answer questions under test conditions to the best of their ability. This means that the qualitative data is generally heterogeneous in nature and requires a close question by question examination to fully elucidate the impact of the experimental conditions on how participants responded to the question. The following section will provide a detailed qualitative analysis of the written questions in the post- assessment test to reveal similarities and differences in terms of how participants in the experimental and control groups responded to the test. This qualitative analysis will focus on the participants' style of answers and explanations and how this impacted upon their respective outcomes.

Full details of participants written responses to all written questions including their explanations and discussion are available for the 46 participants from both the Experimental group (in Appendix 15.A, 15.B), and Control group in (Appendix 16.A, 16.B).

6.2.3.2 Qualitative Analysis of Participants Written Answers to Question 3

Post- assessment test Question 3 stated the following: “Analyze what it means if we have a constant value of schedule variance of 0.75 throughout the project implementation?” The question asks the participant to interpret the indication of a situation in which schedule variance is of a 0.75 value throughout the project implementation. This question was designed primarily to assess participants’ analytical ability according to Bloom’s Taxonomy – that is Level 4: Analysis with a secondary assessment of Level 2: Comprehension. In total 16 participants from the experimental group and 10 participants from the control group answered the question correctly.

A comparative analysis of participant performance in Question 3 indicates a clear difference between the experimental and control group. Participants in the experimental group gave very elaborate and detailed answers relating to project performance. The following will extract some of the participants’ answers in both of the experimental and control groups.

Participants were required to map the values of EV and PV to schedule performance as demonstrated by the following equation SV = EV – PV = 0.75.

Here the answer of Experimental Std. 1 shows a deep level of understanding of the concept of EV and PV:

> *This means that the earned value which represent what is actually have been done versus the planed value and that is good for the project which means the time will be decreased (the project ends early).* (Experimental Std.1)

The written answer to Q3 by Experimental Std.13 is more real life related, and indicates a higher level of deduction where the participant inferred the status not only of the schedule but of the actual earned value also:

> *"SV=EV-PV It's a positive value that means the earned value we have got is larger than planned one. And this is a good sign which mean that we earned time"*. (Experimental Std.13)

Another relevant and indicative answer was provided by Experimental Std.3 who was able to relate the variables to real life implementation and even suggested actions for further project performance improvement 'increasing EV':

> *"It is means that earned value is more increase with planned value it is more better to go positive by increasing earned value more so we can increase the SPI schedule performance indicator and here we are on schedule because the SPI value already near"*. (Experimental Std.3)

Participants from the control group also provided some correct answers, but their written answers in contrast were brief, formula based and without much relevance to the real life implementation of the concept as will be demonstrated by the following examples.

Control Std.4 gave the following short answer:

> *"This means that the earned value is more than the planned value".* (Control Std.4)

While Control Std.15 gave a correct, and brief theoretical answer saying

“That you are ahead of schedule.” (Control Std.15)

Control Std. 23 also gave a brief correct answer:

*“SV=EV-PV=0.75 ahead of schedule”. (*Control Std.23)

These written answers provided by the experimental and control groups demonstrate an overarching trend, whereby the experimental group demonstrate an orientation towards approaching questions from a more practical and real life perspective.

6.2.3.3 Qualitative Analysis of Participants Written Answers to Question 4

Post- assessment test Question 4 stated the following: “Discuss; what are the different areas being affected; when there is a significant amount of error in the project execution?”

The question simply asks the participant to outline what are the different areas that could be affected in case there is a significant amount of errors in the project. This question is not entirely EVM based however it tests comprehension and the inclusive point of view of the participant. This question was designed primarily to assess participants’ analytical ability according to Bloom’s Taxonomy – that is Level 4: Analysis with a secondary assessment of Level 2: Comprehension. In total 21 participants from the experimental group and 14 participants from the control group answered the question correctly.

The pattern identified in the qualitative analysis of Q3 in Section 6.2.3.2 above with participants of the experimental group providing more elaborate and detailed answers to the question is also evident in written answers to Q4.

Experimental Std.1 gave a very elaborate answer which appears to come from a comprehensive ‘system’s thinking’ perspective outlining different possible scenarios pertaining to project health. This outlook on project health tackles different aspects such as time and cost trade-offs both positively and negatively: *“Error may results from bad estimation of time or cost,*

- *If time error:*

There will be delay at the project or the project ends before what was planned.

Delay at the project may cause increase at cost but it depends because the project may be stopped for a while, so the cost will not be affected badly.

If the project ends early this may affect the quality badly or it may be good when the time is appreciated in that project.

- *If cost error:*

This may exceed the budget of the projects which is poor planning and this is a problem". (Experimental Std.1)

Experimental Std.3 gave a correct and elaborate answer however this time they related their answer to EVM terminology from an EVM perspective (although the question did not require or expect this). The student gave the following answer:

> *"Error can affect at Actual cost increase so we will have cost variance with negative it mean project will be costly more Error which affect at earned value make the EV schedule variance with negative so the schedule will be late CPI and SPI with earned value effected because of error and increase at actual cost and less at EV so it will be less than 1 which mean the project not at time and normally cost" (*Experimental Std.2)

Experimental Std.8 gave a very interesting explanation to the question. In their answer the participant states that the error could be mainly due to the Actual Cost or the Earned Value. This shows the participant's level of understanding of the different possibilities and a deep outlook on the root causes of project health issues. The participant then proceeds to explain how low Earned Value or High Actual cost can cause problems for project health:

Participant here answered in Arabic stating the following:

"The error could be because of AC or EV for example if the EV was smaller than what was planned it might case me a problem and it might affect increasing the needed time to execute the project or increase the amount I have to pay in the budget. However, if the AC was more than what was planned, this could cause me a loss or increase the budget I determined." (Experimental Std.8)

In contrast, several participants from the control group gave logically correct answers, but the responses were primitive, reflecting a shallow understanding of the question, with no relationship to the project management perspective and with no reference to EVM:

"May I pay large cost May I take large time to perform a task". (Control Std.2)

"It may take a lot of time and effort the cost may be increase the earned value may be changed". (Control Std.6)

"Lost in time or lost in money" (Control Std.8)

"*Project may take more time than estimate Project may take more money than estimate"* (Control Std.11)

In summarizing the written responses to Q4, participants from the experimental group often gave elaborate and detailed answers grounded in the project management context but written answers from participants in the experimental group were brief and lacked any detailed explanation.

6.2.3.4 Qualitative Analysis of Participants Written Answers to Question 5

Post- assessment test Question 5 stated the following: "If for a certain given project, the Planned Value (PV) is identical to the Earned Value (EV), what does that indicate?

In this question the participant is asked to analyse the scenario in which the Planned Value of a specific project execution is equal to the Earned Value. This question measures the participant's ability to relate project performance indicators to real life project health. This question was designed primarily to assess participants' analytical ability according to Bloom's Taxonomy – that is Level 4: Analysis with a secondary assessment of Level 2: Comprehension. In total 22 participants from the experimental group and 17 participants from the control group answered the question correctly.

For this question, written responses show that more participants from the experimental group managed to relate their answers to real life projects and notions of value than participants from the control group. For example participants from the experimental group gave answers that directly evaluated project performance saying:

> *"Project is on schedule"*. (Experimental Std.9, 10 and15)
>
> "This means that the schedule variance is good". (Experimental Std.17)
>
> *"PV = EV that means the project working as the manager expected and that are no errors in that project and SPI=1 it is an ideal case".* (Experimental Std.21).

In this context language did at times inhibit participants' ability to express them, however for Q5. Participants' answers were more inclined towards drawing relations between variables as well as relating answers to real life scenarios or even sometimes project status, such as ideal projects. Although with all participants there is an obvious lack of knowledge of the project management discipline as a whole, there is clear qualitative evidence that the experimental group condition impacted upon their way of thinking when providing written answers to questions. For example, Experimental Std.1 gave a very elaborate answer identifying a project health case as "ideal" and inferred the meaning of this case and its projection to project health parameters including Time, Cost and Scope. Experimental Std.1 also went on to explain how the different aspects of the project were executed as per the planned value:

“This is the ideal case which means time, cost, scope requirements are all met perfectly. Because this means that the earned value which represents have been done actually according to the planned value” (Experimental Std.1)

In contrast, participants in the control group tended to give more theoretical answers that are generally less elaborate. Answers from the control group mainly revolved around the constants and variables:

“SPI is still constant, equals 1”. (Control Std.6)
“If PV = EV, on schedule”. (Control Std.11)

Control Std.1 gave a very brief answer that only relates to part of the complete analysis, stating:

“On Schedule SV=0” (Control Std.1).

The answer shows that the participant was not able to relate the meaning any further than to the direct relation to a parameter and indicates that participants of the control group are more oriented towards theoretical answers rather than an applied approach.

In conclusion, the comparative qualitative review of the correct answers for both groups shows that experimental group participants are more inclined towards using a systems thinking approach that interconnects multiple variables, and relates these different variables to overall project performance. They also explained the trade-offs among those variables. On the other hand control group participants’ approach to answering Q5 was to take a theoretical, formula based approach.

6.2.3.5 Qualitative Analysis of Participants Written Answers to Question 6

Post- assessment test question 6 stated the following: “For a certain given project, if the ACWP is equal to the BCWP at all points of time, what does that mean?" This question mainly asks the Participant to interpret the significant of having equal values of Actual Cost for Work Performed and Budgeted Cost for Work Performed. This question was designed primarily to assess participants' analytical ability according to Bloom's Taxonomy – that is level 4: Analysis with a secondary assessment of level 2: Comprehension.

A total of 18 Participants from the experimental group managed to answer the question correctly while a total of 15 Participants from the control group managed to answer correctly.

Participants from the experimental group demonstrated a significant edge over their peers from the control group. For example student 1 wrote:

> *"This means that the actually done work meets the actual cost this is planned for it and this is idle and good" (Experimental Std.1)*
>
> *"That I get benefit exactly equal from I paid however it matches the planned value or not" (Experimental Std. 4)*
>
> *"It mean that CV and SV are equal also the performance of the project are equal is same way as cost and schedule depend of the earner value it effect both equally". (Experimental Std. 10)*

The previously stated examples showcase the ability of the experimental group Participants to relate performance variables to the real life project scenarios.

Participants of the control group managed to score correctly on 15 instances. Mainly Participants of the control group gave answers that directly and theoretically address the question. For example; student 1 wrote:

> *"CV = zero, but without time" while student 2 wrote "This mean cost variance = zero" (Control Std. 1)*
>
> *"That mean CV=0 and the project achieve its cost and CPI=1, EAC=budget". (Control Std. 20)*

The previously stated answer examples show that control group Participants adopts a more theoretical approach to addressing the questions; mainly stating formula based answers.

6.2.3.6 Qualitative Analysis of Participants Written Answers to Question 7

Post- assessment test Question 7 stated the following: “For a certain project, if the value of the EAC is double the value of BAC, what does that indicate in terms of CPI?” This question asks the Participant to relate the significance of having an Estimate at Completion that is double in value the Budget at completion. This question was designed primarily to assess participant analytical ability according to Bloom’s Taxonomy – that is level 4: Analysis with a secondary assessment of Level 2: Comprehension.

An overview of the performance across the two groups for question 7 shows that 15 Participants from the experimental group managed to answer the question correctly while only 12 Participants from the control group managed to answer the question correctly. Participants from the experimental group gave answers that are more elaborate as well as more systems oriented. For example Student 1 wrote:

> *“This is not good for the project because it means the earned value is less than the actual cost and this means the cost performance indicator is low “(Experimental Std. 1)*

This is an indicator of a relational approach which connects the performance variables to the general health state of the project (Saying “Good for the project”).

Student 2 also wrote a project health indicating statement, student 3 also wrote:

"It is mean the CPI will equal 0.5 so CPI=EV/AC CPI=0.5 so the earned value will be half the actual cost AC so it not good cost indicator for project and will have negative CV". (Experimental Std. 2)

"CPI=EV/Ac, If the EAC is double the value of BAC, then CPI will be decrease as the value of the actual cost of project increase". (Experimental Std. 6)

Participants mainly tackled the question through real life project scenarios and related their answers to what they perceive as project health or project performance.

Participants from the control group also gave some relational answers however not in a systematic approach; the more persistent pattern of answer came in a more theoretical shell. For example student 6 wrote:

"EAC=2x, BAC=x, EAC=BAC/CPI, CPI=BAC/EAC=x/2x=1/2. Student 14 wrote "CPI is equal 0.5" (Control Std. 6)

Students 19 and 20 wrote respectively:

"CPI=%50" (Control Student 19) and "CPI=0.5, CV= -EV" (Control Std. 20).

This mainly indicates that Participants of the control group are oriented towards addressing questions using a formula based approach compared to the systems or real life approach used by most Participants of the experimental group.

6.2.3.7 Qualitative Analysis of Participants Written Answers to Question 10

Post- assessment test Question 10 stated the following: "In a project, under initial conditions we had a constant Cost performance index of 0.75, after some changes we made to improve performance, the project's Cost Performance Index increased to 1.00, what does that mean?" This question poses a hypothetical situation where a project initially had a cost performance indicator (Index) of 0.75 however after changes were introduced, the project Cost Performance Index moved to 1.00. This question was designed primarily to assess participants' analytical ability according to Bloom's Taxonomy – that is level 4: Analysis with a secondary assessment of Level 2: Comprehension.

A total of 14 Participants of the experimental group managed to answer the question correctly while a total of 15 Participants of the control group managed to answer the question correctly. However although more Participants from the control group managed to answer correctly still there was an evident difference in the approach used in answers.

Participants from the experimental group still used a more relational systems based approach. For example student 1 wrote:

> *"That means that the earned value has raised or may be the actual cost has been decreased in another way the earned value is identical to its planned actual cost"* (Experimental Std. 1)
>
> *"This good because the actual cost decrease after improving performance as CPI=EV/AC"*. (Experimental Std. 6)
>
> Both answers giving an analytical view of project performance shift.
>
> *"It means that the earned value has been increased along with the time which is so good."* (Experimental Std. 20)

This shows that still although the number of correct answers from the experimental group was less than their peers in the control group; the quality of answers from a systems' perspective was obviously higher for the experimental group.

As for Participants of the control group; as consistent with the previous questions, they tackled and addressed the questions from a more theory oriented perspective. For example; student 9 stated the following for an answer:

"CPI = 0.75   CPI = 1   CPI = EV/AC, EV is equal AC, That means the value of actual lost is descried". (Control Std. 9)

Student 8 stated:

"CPI = 0.75   CPI = 1   CPI = EV/AC, EV is equal AC Project improved and successful"

While student 18 stated: (Control Std. 8)

"CPI=EV/AC=0.75, after CPI=EV/AC=1, that`s mean actual value = earned value and commented in Arabic by "The real value = The value of the work completed""

Question 10 still evidently shows that Participants of the control group persistently adopt the traditional approach pivoting on formula and theoretical application of the rules of EVM.

6.2.3.8 Qualitative Analysis of Participants Written Answers to Question 11

Post- assessment test Question 11 stated the following: "What is the relation between the value of the outflow in the previously explained bathtub example and the Cost Performance Index (CPI), the Schedule Performance Index (SPI)?" This question asks the participant to outline the relation between the values of outflow and its effect on the cost performance index (CPI) and the effect of the value of outflow on the Schedule Performance Index (SPI). This question was designed primarily to assess participants' ability to synthesize according to Bloom's Taxonomy – that is level 5: Synthesis with a secondary assessment of Level 4: of Analysis.

A total of 8 Participants from the experimental group managed to answer Question 11 correctly while a total of 7 participants from the control group Participants managed to answer the question correctly.

Student 1 of the experimental group stated:

"If the out flow is low this increases the cost and increaser the schedule performance and vice versa" (Experimental Std. 1)

Student 19 stated:

"I think the outflow effecting on the CPI and SPI if the outflow disappear the CPI will increase also SPI." (Experimental Std. 19)

This answer clearly shows that the participant relates the affecting forces impacting the system to the performance of the activity (Project).

This is consistent with the answer given by student 21 saying:

"CPI=EV/AC, SPI=EV/PV Outflow cause to decrease earned value because it is a less and this decrease CPI and SPI" (Experimental Std. 21)

This is also an answer that demonstrates a relational approach and outlines the effect of the different components on project performance.

On the other hand Participants from the control group gave relational answers on different occasions however their answers were majorly related to EVM formula.

Student 16 gave the answer stating:

"I use 40 litters CPI=EV/AC, SPI=EV/PV CPI=EV/AC AC when out (CPI) Reverse relation with (outflow) (SPI) (outflow) SPI □ oulflow" (Control Std. 16), the Arabic words here refer to "proportional relation"

Student 18 gave the following answer:

*"CPI=EV/AC SPI=EV/PV he commented in Arabic referring to "the excess cost on the project caused Outflow budget"(*Control Std. 18)

Participants from both groups relatively answered the question properly, however; the way to reach the conclusion has an indicative inference to way of thinking to reach such conclusion, where we can find subjects from controlled group relied on a mathematical reading of the equation which could be done to any kind on equation or formula no matter of the subject it reflects, on the other hand, subjects from the experimental group elaborated on the different affected variables that led to this conclusion, in a way they were able to understand the structure not only the symptoms of the behaviour being represented in the formula.

6.2.3.9 Qualitative Analysis of Participants Written Answers to Question 12 & 13

Questions 12 and 13 are joined together in this qualitative analysis as they both target the same Bloom's Taxonomy level of understanding as well as having the same syntax and context (Word Problems targeting the direct application of EVM Concepts). These two questions mainly ask the subject to apply the Earned Value Management Concepts to two similar word problems in order to evaluate performance metrics.

These questions were designed primarily to assess participants' ability to apply concepts according to Bloom's Taxonomy – that is level 3: Application with a secondary assessment of level 2: Comprehension.

The questions were divided over several sub questions:

- For Question 12: four sub questions A, B, C, D asking subjects to compute the values of SPI – CPI – SV – CV.
- Question 13: seven sub questions A, B, C, D, E, F and G asking subjects to compute the values of EV, PV, AC, SPI, CPI, SV and CV).

The two questions have four requirements in common (SPI, SPI, SV, CV) and Question 13 has three extra requirements EV, PV and AC. A total of 145 correct answers were given by subjects of the experimental group while only 75 correct answers for all parameters were given by subjects of the experimental group. Performance comparison across both groups strongly indicate that subjects of the experimental group had a more thorough understanding of the concepts of

EVM as they achieved better results extracting problem givens and applying them to the EVM corresponding equations. Although no narrative answers were required in this question, a tangible difference and a pattern is seen in the answers provided by subjects of the experimental group as most of the subjects wrote the complete equations for solving the question as opposed to the subjects of the control group. For example Student 1 of the experimental group wrote as in the answer to Q.13:

"SV = EV – PV = 170 – 250 = -80$" (Student 1)

Student 4 Wrote (Question 13):

"SPI =EV/PV=0.68

CV= EV-AC= -105" (Student 4)

Student 6 Wrote (Question 13):

"*CPI=EV/AC=170/275=0.618)*

SV=EV-PV=170-250= -80" (Student 6)

Student 12 Wrote (Question 12):

"SV=EV-PV=150-100=50

CV=EV-AC=150-120=30" (Student 12)

Student 17 Wrote (Question 12):

"SV=EV-PV=150-150=0 (Student 17)

CPI=EV/AC=150/120=1.25 (Student 17)

SPI=EV/PV=150/150=1" (Student 17)

The previously shown answer samples across both questions show that subjects of the experimental group used complete forms of equations to answer the two questions.

Subjects of the control group on the other hand managed to score a total of 75 correct answers versus 145 scored by their peers in the experimental groups. The answers given by the subjects of the control group were comparatively brief and did not use the complete form of the equations in most occasions. Student one wrote in the answer to Question 13:

"EV = 170

PV= 200

AC = 280" (Student 1)

Student two wrote (Question 13)

"EV = 40 + 50 + 80 = 170 $" (Student 2)

Student four wrote (Question 13)

"PV = 50 + 100 + 100 = 250" (Student 4)

Student eight wrote (Question 13)

"EV = 40 + 50 + 80 = 170 $

PV = 50 + 100 + 100 = 250$

AC = 60 + 88 + 42 = 190$" (Student 8)

Student 12 wrote (Question 12)

"SV= 150-100=50

CPI=150/120=5/4=1.25

SPI =150/100=1.5" (Student 12)

Student 20 wrote (Question 12)

"CV=120-100=20

SV=120-100=20

CPI=120/120=1

SPI=120/100=1.2" (Student 20)

Looking at the possible reasons behind this pattern in the answers and reviewing the delivery of training for the two groups, it is found that during the delivery of the SD based training for the experimental group; subjects of the experimental group were more exposed to the full form of the equations while using the SD models in simulation; while subjects of the control group were not. The following are some snapshots of the interfaces that the experimental group candidates were exposed to while working with the SD models showing full form of the EVM equations in Fig. (18) and Fig. (19):

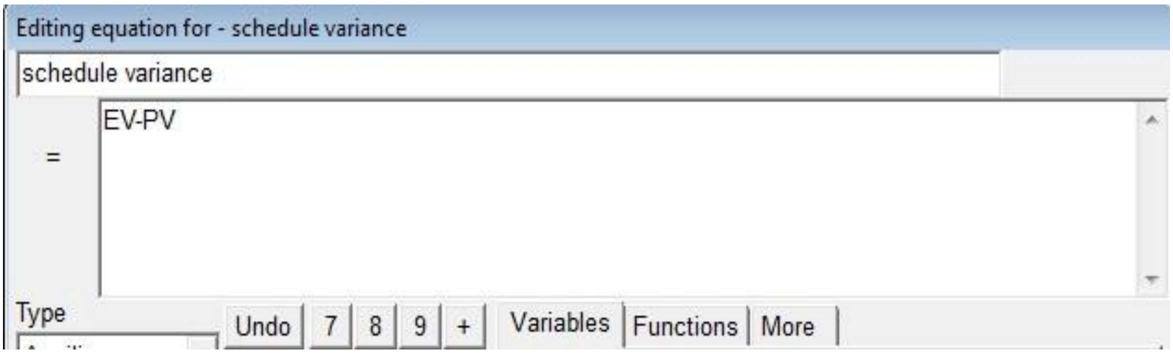


Figure (18): During Lesson Screen Shot 1

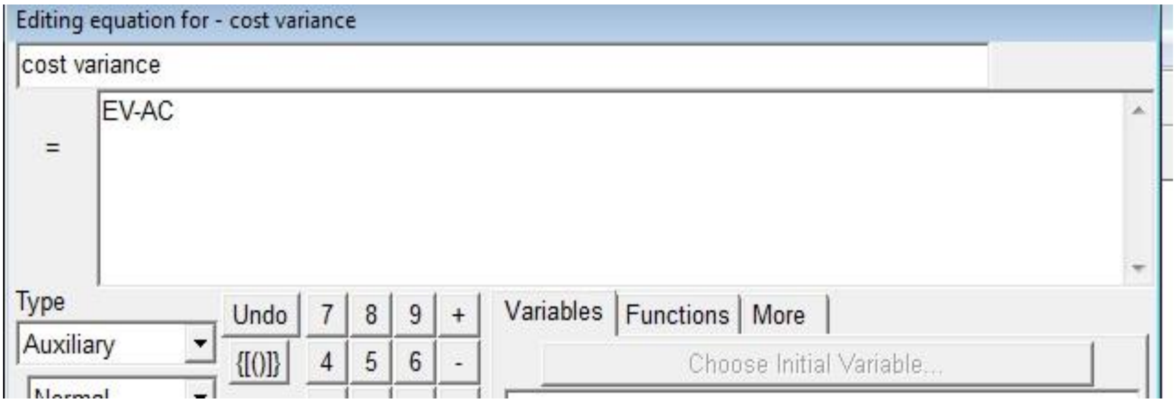


Figure (19): During Lesson Screen Shot 2

Subjects were also exposed to the effects of manipulating the variables and the inputs of the different models and they noted the effects of manipulating those variables on model performance. Subjects were exposed to graphs such as the following Fig. (20):

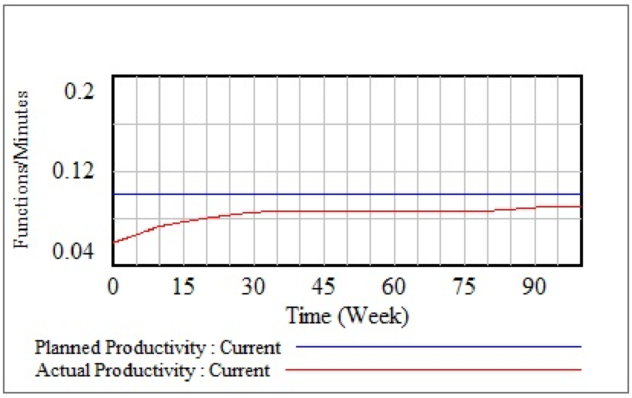


Figure (20): During Lesson Screen Shot 3

Subjects of the experimental group were able to manipulate model inputs such as “Number of Developers”, “Attrition rate”, “Productivity”. Upon the change of inputs induced by subjects, they were able to see how that change affects project behaviour. For example:

- When the number of developers is reduced, the actual productivity (Plotted in red) demonstrated in “Functions/Minute” (Y-Axis of the graph above on the left) becomes less than the planned productivity (Plotted in Blue).
- Subjects were then asked to infer the effect of such a performance change on the Earned Value of work or how will this affect schedule or cost variances.
- As subjects were constantly exposed to the full forms of equations and were always able to visualize the effects on project performance metrics; they were able to correctly infer relationships and performance impact.

Another example is shown in the following Graph showing the actual number of staff in a company over time (Plotted in blue) versus the planned number of staff (Plotted in red). Subjects were able to manipulate the attrition rates and staff hiring rates affecting the number of staff.

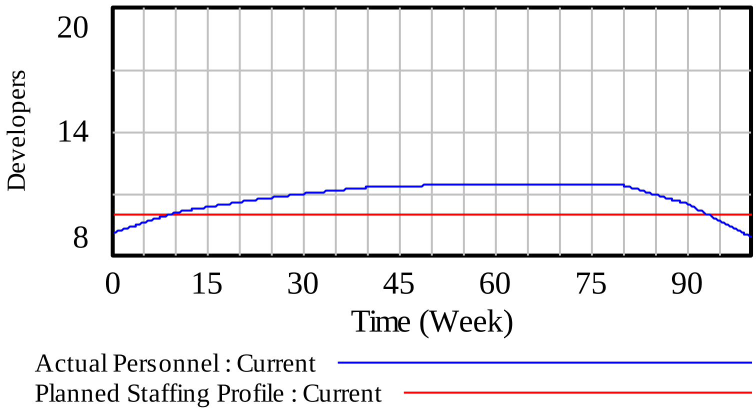


Figure (21): During Lesson Screen Shot 4

Subjects were then asked to infer the effects of having a staff curve different from the planned curve and the implications of this change in terms of EVM metrics.

A very persistent indicator of performance difference between subjects of the experimental and control groups is the performance of subjects in extracting the values of EV, AC and PV. This shows in clear contrast that subjects of the experimental group had a deeper understanding of the real life givens of the questions asked. Subjects of the experimental group scored an average of 0.5791 versus an average score of 0.2898 scored by their peers in the control group. This indicates that subjects of the experimental group were more proficient in extracting the values of EV, AC and PV from the given information in the question.

6.3 Summary and Conclusion

From the demonstrated results in the above sections, it is shown that for most of the majority of the participants from the experimental group did reflect on their way of explaining and answering the questions using system thinking concepts and terminologies in terms of recognizing the effect of relations and causalities between variables. Realizing these relations was used in answering some questions in an interesting level of awareness, like for example with the case of Experimental Std.8 when was answering question number four, the student's answer shows deep level of understanding of the different possibilities and the root causes of project health issues. This level of qualitative privilege in the answer of experimental group was supported by the quantitative statistics of their post- assessment test scores.

Looking over the whole experiment, it became evident that a key factor leading to the performance difference between the experimental and control groups was the visualization of relationships and the continuous reinforcement of system's thinking skills.

Counting as a vertical reinforcement of information and knowledge, the experimentation models aimed to constantly enable the participant to digest incrementally different SD models varying in complexity and size to prompt his/her thinking approach in terms of systems thinking. This kind of continuous exposure and practicing acts as an exercising specific set of skills in a continuous way.

The output of such approach in the experimentation was expected to be evident mainly in questions that are measuring the understanding and the analysis of a certain context– as could be seen for example by looking at questions number 7, 8, and 9 - but not necessarily the questions measuring the direct memorization of concepts for example as happened with question number two which could be just easily answered no matter what kind of external assisting learning intervention was used having good skill of memorization.

One of the unexpected outcomes found in the experiment's results is the higher scoring records of the experiment group participants versus the scores of the controlled group participants. What is interesting here is; there were no previous expectations for the probability of achieving better results for one group versus another one, knowing that this is an application type based question, so it was very much expected to have any one with a good memory to just follow the equations in his minds which will not necessarily imply any underlying understanding.

Unexpectedly; having this significant difference between both groups in this specific question - subjects of the experimental group scored an average score of 0.5791 for subjects from experimental group versus an average score of 0.2898 scored by their peers in the control group – led to further analysis that was previously explained in section 6.2.3.9.

On the other side, the scores showed inconclusive results regarding other set of questions number 1, 2, 11. There were no major differences in these questions. Almost both groups got similar scores. Actually it was of interest in this case to analyse qualitatively the subjects' data sheets who didn't score these questions right. However; having these questions in the format of multiple choice without giving chance for the subjects to elicit their way of reaching their answers; hence; investigating more about their way of thinking and the underlying level of understanding didn't allow for this level of analysis. This is one of the recommendations that need to be considered when designing the research instrument in the future work.

Also SD didn't prove its ability to improve the skills of the experimental subjects in each of the questions number 8, 9, and 10. Prior better design for these questions would have definitely help in analysing these cases. However; it is clear from the results that the difference is not that significant; however; one of the reasons for this slight difference could be due to the quick handling of models to these parts of EVM's indicators (CPI, SPI) and their role to project the future project performance. Also having these questions designed in the form of multiple questions doesn't reveal so much about the way of getting to these answers.

In conclusion, the quantitative and the qualitative results supported the initial research hypothesis related to (i) achieving higher scores in their post-assessment tests' scores, and (ii) improving the understanding and the learning subjects' skills mapped to Bloom taxonomy. Moreover; (iii) the way of answering, proved supporting understanding level of the learners about the structure and not only the symptoms of the behaviour as was clear from question 11, the depth of elaboration in the learners' answers using the concept of relations between the different affecting variables and the chain of causalities governing these relations is of another indication to the change of their mindset that is being now more causal based rather than mere listing structure oriented, this factor was not initially listed in the hypothesis, however; in light of the qualitative analysis, it worth mentioning adding this up.

The whole set of positive, negative and the inconclusive findings help to formulate set of guidelines, insights and feedback for other interested tutors, developers or researchers in the same field will come in the following next chapters.

Reaching the step of analyzing the study's results w.r.s.t. the initial hypothesis Fig. (22) prepared a good base now for soliciting the learnt lessons that will guide for further work.

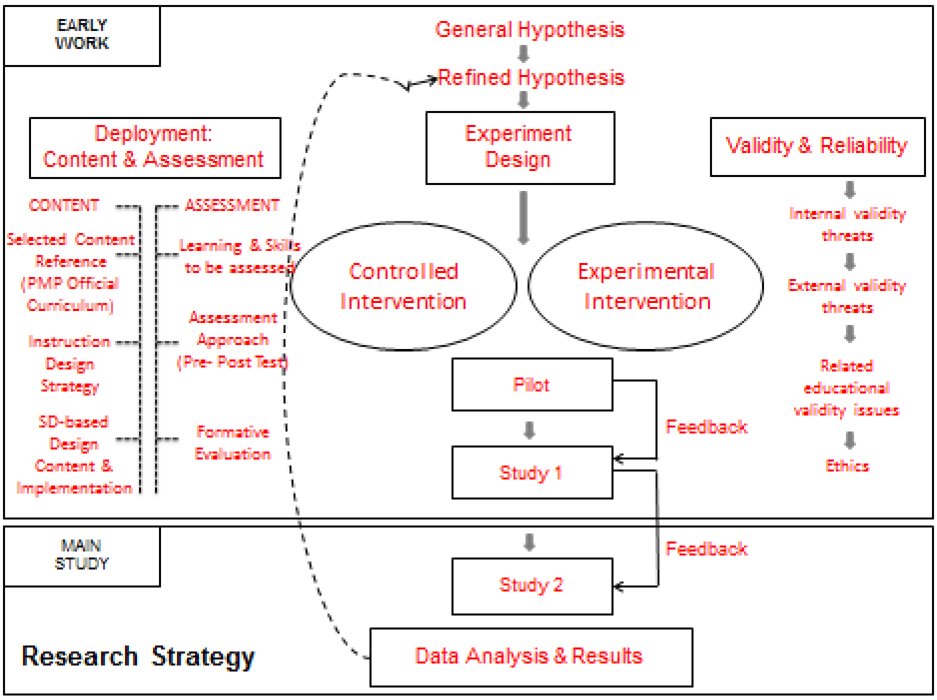


Figure (22): Feedback and Results

Chapter 7 Guidelines for the Deployment of SDs Simulations in Project Management Education

7.0 Overview

The results obtained from the experiment indicate an advantage in favour of the experimental group over the control group as outlined in Chapter (6). This advantage was expressed in the quantitative and qualitative outputs of the assessment conducted as well as the feedback provided by the tutor prior to and after the experiment.

Based on these results and the feedback of the tutor, this chapter aims to provide a set of guidelines for other researchers in the same field, project management learners and other tutors who are looking at trying to use SD based learning.

7.1 Scope of Guidelines

This set of guidelines will be mapped to the previously mentioned goals in Chapter (3) and reflect on the following:

I. The suitability of the content and approach,
II. The appropriateness of the design in terms of:
   a. The Experiment Design
   b. The Assessment Technique
III. The readiness and the appropriateness of the learning context.

7.2 The Suitability of the Content and Approach

7.2.1 The Choice of the Content

The selection of the content is important from two main perspectives; (i) to ensure that there is a real challenge that drives looking for other non-traditional ways of delivery and unorthodox approaches, and (ii) from the type of the challenge that is being addressed. These two variables formed a prerequisite for the selection of the simulation technique that will be used. Here, EVM as a topic was affected by the dynamic nature of its interacting variables of the scenario case that is being studied, this is the reason for selecting it for this study, and the challenge of having continuous changes between the affecting variables was the reason behind the selection of SD as the simulating tool for the experiment.

The tutor feedback supported this saying:

> *"It is very challenging to address students with topics related to project management before making sure that they get the time to assimilate themselves and mind-sets into thinking "Projects"*

Although the words "Thinking projects" are simple, yet it entails numerous features and characteristics that are coming from the nature of 'projects' as a complex topic. This way of practicing, dealing, and trying out complexity is what is meant by "thinking projects"

Also, a need for practical tool that would enable visualization was in favour to the second aspect of the previous guideline that is as reflected in the tutor's opinion below:

> *"The lack of a proper visualized approach to project management. We find it very tricky to teach real life concepts and scenarios through traditional pen and paper as well as without sufficient practical reference".*

The matchmaking between the content and the simulation technique was reinforced through the tutor's feedback after using SD:

> *"System Dynamics empower the instructor not only to give vivid simulations of the interrelations and interdependencies but also empower the student to be a part of the model. This means that students can actually see firsthand how decisions and variables affect real life behaviour".*

To summarize, the synchronisation between the simulation techniques and the type of challenge within the topic taught is a key factor to decide before implementation. The level of challenge offered by EVM as a project management topic is, thus, a key influencer on testing the impact created from implementing SD-simulation based learning environment.

7.2.2 The Selection of the Simulation Technique

The potential of SD as a simulation approach in addressing EVM challenges is not absolute. Each simulation technique suits a specific purpose (as explained in details in Chapter 3) otherwise, this causality relation between the target and the way to realize it - which is the main hypothesis in the current research study – will not be valid anymore.

As discussed in section 2.4.3, there are different critiques for SD; however, all the simulation tools in general and SD in specific cannot be assumed valid or effective across all disciplines. Each one of these simulation techniques has its own limiting conditions for maximizing its potentials and ensures its validity. SD goes beyond the functionalities of the spreadsheets and provides an interactive environment for visualizing, monitoring, and projecting the different scenarios and behaviour of dynamic systems. This specific feature might not be of high impact if applied on topics of non-relational nature; this is why, selecting the right topic for the right simulation technique is essential.

On the other hand, EVM is recognized as a powerful tool that provides visibility for resource costing and activity scheduling, yet difficult. However, it is also known that it is an overwhelming topic to learn due to its mathematical equations that govern set of relations between different variables of resources and schedules (Mo, 2014). It is worth mentioning that the complexity of EVM is not necessarily caused by its complex mathematical formulas, but is mainly because of the trade-off relationships that exist between its various components. Both text based lectures and scenario based real cases are only reinforcing the usage of these equations without enabling the students to explore or try the dynamic relations that govern it.

This sense of practicality could be seen from the participants' feedback, Exp. Std. 2 expressed his interest in learning more based on new concepts that were not introduced to him before. On the other hand, Control Std. 2 expressed his willingness to learn how to apply the EVM concepts in real life situation. Control Std. 3 asked about how to apply EVM in new projects, also Control Std. 5

wondered about the availability of having some sort of software for EVM, while Control Std. 6 asked for real examples. In light of the previous, it is safe to hypothesize that it is important to match make between the challenge and the proposed action. In this case having EVM characterized as a complex topic in terms of its underlying dynamic relations nominates the usage of SD teaching based to address such challenges.

As mentioned before, the possibility of visualizing relations and giving the opportunity to learners, tutors, or users to be more engaged were endorsed by the "Tutor", which was apparent in his opinion before the experiment:

> *"I was somewhat skeptical about the actual and true effect of using SDs modelling and if it really will make a significant difference…this question kept lurking in the back of my mind for a significant amount of time".*

During the experiment, he commented on students' behaviour by saying:

> *"One of the most refreshing aspects of the training delivery experience was to see students feeling engaged and motivated to actually experience and infer relations between variables".*

One might say, that this is expected, giving something to 'play' with definitely will be of more interest. However, this might be valid during the first few moments of the experiment, knowing that the same level of the claimed 'playing effect' will go with both cases, learners working with SD models and others working with 'Spreadsheets', but this level of engagement would not last if the whole session was not progressively adding to learners' skills, and it wouldn't continue to reflect on the qualitative and the quantitative results as seen in Chapter (6).

To sum-up, SD is not the solution for all cases and at any time, the match making between the selected challenging topic or the investigated problem and the features of the selected simulation technique is a critical decision upon deciding the best modelling technique.

7.3 The Acceptability and the Appropriateness of the Design

7.3.1 The Bottom up Design Approach

This approach is commonly found with content instructional design and modelling design, which is closely related to the cognitive load of a learning process. The effect of having a gradual approach was evident after the first pilot experimentation and the early designing phases of the experiment (Pilot 1 and Pilot 2). This gradual approach improved the learner's grip on learning objectives without being confused due to the content load, and helped the subject to mitigate the shock of seeing a complicated model without passing through its early simple seeds of modelling in a gradual way till reaching the final form.

This conclusion is in alignment with the gradualism theories of simulations' design.

7.3.2 Reinforcement of Learning

Learning reinforcement means the usage of different activities of practical examples, in the form of near and far contexts as well as real life cases to create an impact on the learning and retention skills. Providing different practical examples in a gradual way that is in synchronisation with the gradual design of the content helped to reinforce the initial designed learning objectives. Reinforcement is always vital, it was represented in the discussion occurred at the end of each chunk of a learning session.

It was of importance for both groups to have this level of reinforcement, whether through SD simulation based models, or paper based scenarios. As explained in Section 4.2.3, Table 2 and the lesson plan for both groups (Appendix 11), using different near and far context examples is an important factor and should be considered with both ways. Repeating near and far examples for the key aspects of the content will ensure that learners learn the key ideas and concepts that are conveyed.

7.3.3 Available Content Material

The availability of the detailed instructions is important in many ways. first, it helped avoiding wasting any time of probable unplanned activities, as occurred in the early pilot experiment when there was no prior guidance for either installing the models before starting the lesson, or presenting properly for the learners what will happen before letting them try the models themselves. Overlooking these details caused wasting time compared to the planned time for the session.

This will save time as occurred in the study and confirmed by the tutor, while talking about the difficulties faced:

> *"Significant assimilation time was required for them to get more adapted into the simulation environment. Having no background in simulation; and being exposed first time to simulation software slightly impacted their ability to manipulate the models freely. This resulted in some inhibition which took some time to overcome".*

The availability of the learning material in details is of importance for both the tutor and the participants, in a way that ensures no delay, and allows for independent learning with minimal interventions from the tutor in the relevant exploratory and practical learning aspects.

In summary, detailed guidelines helped in regulating the time of the experiment without being distracted due to the absence of needed information.

7.3.4 Reinforcing Activities

The addition of several reinforcing activities is of impact on helping the learners to apply what they are learning and add up to their own work context as shown in section 4.2.3, Table 2, for example with the subsections titled 'B.3 Exp.', and 'B.2 Ctrl.'

These opportunities allow for self-explorations; that help in engaging students, as was clear with the feedback of 'Colleague 2':

“The subject found this approach to be easier as it gave a more “real life” flavour to the topic and helped in visualizing the real implications in the variation of the different variables”

This matches the feedback from the tutor when he commented on the learners’ attitude during the session saying:

“The reactions of students were completely different when they started seeing and experiencing information delivered through simulation. Students seemed to be particularly interested in the parts through which they were able to manipulate scenarios and experience their effects on project performance”.

In conclusion, adding reinforcing activities and assessment is one of the recommendations that will help in improving the level of understanding for both groups using different types of delivery, whether through the SD based models or through the examples that will be addressed using pen and paper.

7.4 The Assessment Technique

Giving attention to the design of the assessment tool helped in producing accurate learning evaluation results and provided for a detailed understanding of the level of improvements and progress that occurred for each of the involved participants.

7.4.1 Pre-Assessment

Apart from the known roles of the pre-assessment, conducting this experiment with heterogeneous segments of participants (in terms of their educational background’s levels) resulted in the need to assess more skills as in the current case.

The pre-assessment was used to ensure having homogeneous profiles of the experiment’s participants. However, at some point of time as happened in (Pilot II), it was important to alternate the pre-assessment, to ensure that the prerequisites of the subjects in terms of their numerical and logical skills are different. This alteration aims at gauging the participant’s ability to perform the mathematical and logical operations that are needed while performing EVM calculations. This was recommended by the tutor at that time, after reflecting on extending the length of the pre-assessment, this extension was not essential during the final experiment once making sure of the participants' background, hence, this allowed for focusing only on the required skills needed prior to real implementation.

In this study, having the learners from background relevant to this kind of skills technical background faculties - doesn't necessitate this kind of change with the main study.

7.4.2 Post-Assessment

Having depth in the post-assessment instrument in terms of giving more chances to the subjects to reveal and elicit their way of understanding and rationalizing their way of getting his answers, consequently helped the research and the tutor to determine (i) if the participants reached correct or wrong answers based on their level of understanding rather than mere trial and error, and (ii) probe deeper to discover more about the participants' mind-set and the way of thinking they used to reach their conclusions.

Also, relating the design of the assessment instrument to the overall intended learning goals is important in setting and assuring the focus, hence, the expected output from the assessment results.

In the early formative stages of the experiment, the assessment questions' design was meant to assess the systems skills and SD more than the topic itself, so for example several questions were designed to address the learners' understanding about "Behaviour over time", "Linear growth", "Continuity", "Accumulation". This was clear from the nature of the questions at that stage (Appendix 11.B) as for example:

> *Part A: Question 1: Explain the relation between the hiring (inflow) and leaving (outflow) based on the given graphs?*
> *Part A: Question 6: "Giving the hiring of the employees is changeable in a nonlinear pattern as in the following graph, and having a constant value of*

employee leaving, Infer about the net number of employees changes over time"

Part A: Question 3: Predict the result (what happens) when the hiring flows in the current employees at a greater rate than it is leaving based on the given graphs?

Part A: Question 4 "Analyse this case; if the employees are leaving at a faster rate than new employees are hired and allowed to be performers, the stock of project employees will go down?"

Although, these types of questions have an indirect impact on the understanding level of the underlying relations that govern the scenario being discussed, it created the expected imbalance in the learners' results having the experimental group practicing this direct questions in Part A. From another point of view this will position the assessment of the accumulations, causalities, and other systems thinking skills in the first place rather than the topic itself, hence affecting the initial hypothesis.

This is why, it was directed by the tutor to have the question in the post-assessment (Appendix 7) more about EVM, hence, neutralising the final findings.

7.5 The Overall Evaluation Phases Structure

It was important to go through deep iterative evaluation stages as explained previously in Chapter (5), in terms of the different levels of piloting and external stakeholders such as: SD specialist, project management specialists, junior and senior training and educational specialists. This helped in amending the initial planned experiment and increased the likelihood of producing accurate, appropriate experiment and minimized the probability of having serious design issues affecting any of the experiment phases.

Highlighting on the uniformity of participants' not only from the topic's perspective, but also considering their cultural and educational differences, was one of the tutor's input that affected the early stages of the pre-assessment.

Having the tutor and the project management specialist was of impact so as not to be inclined to assess the systems' skills in a way that affects assessing the topic itself. Encouraging the idea by two experts in the field was of impact on boosting the research forward.

To sum up, having different stakeholders is essential to validate, assure, add up and assess the different stages of work. Planning for the pilots of implementation should be accurate, and should be considered as a part of the whole research design from the early beginning.

7.6 The Learning Environment

7.6.1 Proper Readiness of Class Environment Prior to the Implementation

A time delay was experienced during the early piloted phase – Pilot I – this was because of the absence of the training material in a well-prepared form on the laboratory computers. This affected both the planned experiment timing and caused initial distraction for the participants; which affected further delay. This could be easily avoided if the training material was previously loaded on their equipment.

The tutor needs to pay attention to the introduction part of the session so as to guide the participants from the experimental group to start working with the practical simulation models. Controlling the launching period is of importance in order not to cause any unexpected problems or alteration in the planned teaching scenario, and to share and convey a proper communication to the subjects' from both groups in a way that will not cause any kind of frustration to the subjects from the controlled group. This proper messaging will help avoid affecting the subjects from controlled group's willingness to get engaged with the experiment in advance, hence, affecting their performance and results during and after the experiment.

Also the selection of the used software in terms of its availability to facilitate the engagement of the experiment users helps them access the software with no logistical issues as they expressed in their feedback. Working with VenSim as a free tool with accessible community for any further inquiries was of help and facilitated the usage of the underlying work.

7.6.2 Equal Environments for Both Groups

The current research relies on assessing the impact of one independent variable. This is why it is crucial and of high importance to control the complete set of affecting variables that might interfere with this independent variable.

The usage of SD as a teaching based methodology is the sole independent variable, which is being assessed through two groups; therefore; it was important to provide similar learning context environment for both groups.

In section 3.2, more details were discussed about the validity of the experiment and how to control the confounding variables in a way that secures the independent variable being assessed and maximizes the validity of the causal relation between SD as a teaching tool and the learners' skills. The section discussed the internal and the external validity factors that should be considered. This is why; the various amendments that have been taken all the way through the formative evaluation phases of the experiment, these discussions were transferred into actual implementation in terms of:

- Making sure of having one non-biased tutor after conducting the first pilot – Pilot I, also the tutor should be someone other than the researcher,

- Making sure of providing a similar technologically supported environment for the two groups, the usage of the computer in Pilot I was only to support the SD models with the experiment group, whereas there was no computers with the control group, which is considered as one of the biased factors. After, Pilot I, the computers have been used as a presentation medium for the used tutorial,

- Making sure of having equal exposure to the level of data visualization for both groups was one of the recommendations after Pilot I. This is why, the lesson for the control group has been amended to include visualized examples using the Excel spreadsheets.

The effect of these three factors was discussed previously in section 3.2.1, and how it can manipulate the experiment if not considered thoroughly in a way that will affect the responsibility of the independent variable on the observed results.

In summary the following set of guidelines should be taken into considerations when aiming at doing similar experiment:

- The synchronization between the simulation techniques and the type of challenge being faced as a part of teaching certain topic is a key factor to decide before implementation;
- SD is not an absolute solution, the match making between the selected topic's challenges and the features of the selected simulation technique;
- Gradualism is essential to the design and preserving the learners' cognition load;
- Using different near and far context examples, where the learners use and apply what was learned in direct example and situation, and implement it in different and far situation settings from what was given before. This is an important factor that should be considered with both ways and both groups. Repeating near and far examples for the key aspects of the content will ensure that learners learn the key ideas and concepts being conveyed;
- Detailed guidelines helped in focusing the time of the experiment without being distracted due to lack of needed information;
- Reinforcing the learning through activities and assessment is one of the recommendations that will help in improving the level of understanding for both groups using different types of delivery, whether through the SD based models or through the examples that will be addressed using pen and paper;
- Pre-assessment is important for the uniformity of both groups and within the same group of participants. Also it is important to conform the

participants' prerequisites to the experiment's requirements, especially with different educational system and cultural variances;

- It is important to have post-assessment approach that is related to the study objectives as well as the learning objectives;
- Including diversified experts with clear objectives from the early formative design phases is of valuable impact on the whole experiment;
- Detailed instructions secure focusing on the required objectives with minimal margins of time waste.

7.7 Summary

This chapter aimed at benefiting from the experiment and its early development phases and summarising this in the form of guidelines. In chapter 5, a discussion was done about the details of the formative phases of the experiment, and the relation between each of these development phases to the mostly affected key formative goals; Goal I: the suitability of the content to the experiment, Goal II: the usability of the SD models and the equivalent activities for the control group, Goal III, the readiness and the appropriateness of the learning context for both groups, and finally Goal IV: the overall look of the experiment and the testing. A summary for these development phases and its relation to these goals has been presented in Table 8.

This chapter adds to Table 8 further dimension; which is about providing a set of guidelines for researchers, developers, tutors, and new learners in the field of project management and system dynamics. The chapter summarized different aspects of guidelines that resulted from the early developments of the experiment that contributed in maximizing the internal and external validity of the experiment design. In addition, the feedback of the participants, experts, and tutor added different aspects of contribution in a way that helped reaching better design for the models as well as the testing instrument. These guidelines have been categorized in light of the experiment key formative goals to address; (i) the content and the modelling technique selection considerations, (ii) the design of the experiment lessons and assessment instrument, (iii) and the learning context for both groups.

Chapter 8 Contributions, Lessons Learned, Further Work, Research Issues and Conclusion

8.0 Overview

This chapter will review the main study contributions, and present the conclusion of the study results and show how these results contributed in this research area with a ground work assessment that was needed in different research calls, and proved the main study hypothesis.

In light of the study roadmap that was explained in chapter 5-Table 8, and in light of the different expert engagements and feedback, the chapter will present a set of recommendations for potential future work in the field of SD based learning in general and in the field of teaching project management using SD in specific.

The chapter will also show how this ground-work contributed in the development of SD models, teaching material and assessment techniques that are considered as a practical guiding process for other workers and contributed in reinforcing the findings of other theoretical calls in the area of using SD in PM teaching. The study contribution presented in this chapter will be explained following the main study contribution structure that was presented in Chapter 1, section 1.7. The chapter will also review what has been learned; suggest the future possibilities for further SD learning development experiments. To conclude, some practical research issues which have been of relevance to this study will be reviewed.

8.1 Contribution

8.1.1 The Main Outcomes of the Hypothesis Testing

The mentioned hypothesis in Chapter (3), section 3.1 proposed that using SD simulations to teach project management will help supporting the learners to achieve higher scores in their assessment.

These high scores resulted from a deep thorough study with forty six participants who were randomly assigned on two groups; the experimental group and the control group. The performance difference was quantitatively proved in favour of the experimental group; that was clearly shown in the areas of understanding, analytical, and application questions.

In addition to the quantitative assessment results, there is another dimension that is considered very important on its contribution, which is the qualitative assessment results and analysis that were extensively explained in chapter 6 starting from section 6.2.3.1 to section 6.2.3.9. The importance of this contribution is coming from its impact on leveraging the confidence in the quantitative assessment values and meaning; it assures that these results are not a matter of trial or luck; they are a reflection of the participants' level of understanding and digestion to the taught lesson with the new approach.

These qualitative results showed the ability of the learners from the experimental group to rationalize what is going on and their ability to understand the "Know-How" of the various aspects and the way they affect each other. Moreover; the way of elaborating on the questions that were solicited from the experimental group assured a different way of thinking and reasoning while reaching the conclusion or explaining issues. This way of elaboration, as explained in Chapter (6), reflects causal way of thinking and another level of understanding of causalities, and dynamic interactions.

8.1.2 Guidelines for the Development of SD Learning Based Environments

In chapter 5, there was a detailed explanation about the early development phases of the experiment, and how it was developed in cooperation with different domain experts until reaching the final experiment form. Benefiting from this and from the whole experience in planning, implementing, assessing, results generation, and the communication with different experts with their different views helped in backing-up the results and coming out with a clear set of guidelines explained in chapter 7 that were mapped to the different developmental goals of the experiment design:

- The suitability of the content and the Approach,
- The appropriateness of the design in terms of:

- The Experiment Design
- The Assessment Technique

- The readiness and the appropriateness of the learning context.

The eleven different subcategories of guidelines that were presented in chapter 7 would be of great help to other workers in this area. The guidelines are not comprehensive, yet they will assess other learners, SD models, and teachers. They will benefit from the overall process that explains, the selection of the topic and modelling technique, the experiment design and its assessment, and the design of the learning experiment for both groups in a way that will maximize the confidence of the independent variable assessed in this study.

8.1.3 Contributing to the Existing Theories and Work

There are different contributions in the field of using simulation in learning and different work in the area of SD simulation techniques in teaching project management, yet; there is a need for further empirical studies to assess the impact of these experiential learning techniques on the learning skills of students. This need is growing in light of the limited available assessed simulation work based on grounded evidences as opposed to descriptive studies (Issenberg, et al., 2005, Landriscina, 2013).

This study contributes to fill this gap, and with its results it reinforces the descriptive expectations and other contributions' findings. This ground-work contributed to provide:

- The development of an approach that creates more practice-aware generations of project managers yielding better understanding and performance, through a detailed learning content for the delivery of the lesson for both the experimental and the control group. This content will be of benefit for learners or tutors who are interested in going through the SD-simulation based for project management.
- The development of a series of SD's models that would be of help to the interested developers who are looking for further exploration in relevant fields. Such models serve as a seed to future developments in the area of project management teaching using SD and could be of help if applied to

different areas in project management. This will help create comprehensive model libraries for different project management areas and concepts.

- The development of a groundwork assessment instrument for evaluating the effectiveness of teaching project management using SD exploiting Bloom taxonomy aiming to explore the most affected cognitive learning skills. This assessment instrument can be considered groundwork for further assessment work that depends on assessing the learning skills of the selected topic, and not only for assessing the system thinking skills.
- The methodology with its results contributed to defending the SD criticism, as the results showed in practice how SD's commitment to mathematical relations is not against the relational ontology. This was clear from the qualitative analysis of the post assessment participants' answers, which defends SD's capabilities through a practical assessment and analysis.

8.1.4 Contributing to the Country Needs of Well-Trained calibers in the field of PM.

In light of the Egyptian information and communication technology sector needs and strategy, this study, contributed to creating good project managers in a way that would bridge the gap between the dominating learning approaches in this field and the expected level of practical understanding that suits the needs of real life.

8.2 Key Lessons Learned

The following will tackle the key lessons learned from the whole experience of being introduced to this field, planning for the study, implementation' successful and failure stories, assessment, and writing up.

8.2.1 Synchronization between the Selected Topic and the Used Technique

Having the chance to be a member in a project that provides different system thinking concepts and techniques for a group of middle management seniors, introduced the researcher to two related domains; concepts of thinking in systems patterns and paradigms, and a spectrum of different techniques to practise these thinking concepts including lateral, vertical thinking tools, problem solving approaches as well as soft and hard system approaches. Applying this with project managers, who used to work with realities, showed the researcher the importance of relating both concepts with the underlying techniques. Making an analogy to the current study, the decision of selecting the Earned Value Management to be modelled using SD, helped the learners to appreciate the close relations between the projects' concepts that were used to introduce in terms of the cases in real life and their ability to try out these concepts through the underlying practices and models of SD.

The careful consideration of integrating the topic's choice and the choice of the technique to address specific challenge was of importance. One of the main project management functions is to continuously evaluate the achieved target with consideration to the available resources without hindering the overall goal of the project. It is intriguing to learn that managing projects is best done through groundwork. On many occasions, decisions needed to be taken on either to drop out or to add up some of the features to the design of the experiment, and this was always judged in light of the constraints of time and resources, and most importantly was recognizing the way to always balance between such dynamic changes and the effectiveness and validity of the overall research target.

8.2.2 Detailed Guiding Instructions

Another learned lesson is related to the pre-activities of the development phases of the research. In Chapter (5), the different phases of the experiment's evaluation was actually developed in iterative cyclic phases, however; setting out a clear roadmap of the different needed interventions and insights from the multiple potential experts, practitioners, and volunteers would contribute to shorten the time taken for the on-going amendments. Indeed; it is most likely to have dynamic changes all the way along the study, however; giving considerable time for setting out work roadmap will minimize the further possible need of later changes, hence; less time spent on changing, and while focusing efforts on the road ahead.

8.2.3 Participants' Commitments

At the beginning of the study, participants' commitment was taken for granted. However, unexpected delay happened during the early pilots due to the lack of some participants' commitment. This alarming fact made it inevitable to ignore such aspect throughout the research. It was of importance, to write up a detailed document that includes the full steps of the experiment in advance. However, the information was conveyed verbally. This was not enough, it was important to give clear data and information about the nature of the experiment, the timing, and the importance of committing to it. Providing this through a well-written document, would have ensured a better understanding for the level of commitment, rather than elicit a quick unevaluated decision of volunteering on the participants' side. Also, it is important to consider the information that could be shared. For example, the kind of information related to the difference between the two groups of the experiment, might create a kind of initial judgement, at the same time it is of no relevance to the purpose of leveraging the commitment and ensuring the participant's right of sharing the required information.

8.2.4 Pre-Assessment Tool

The pre-assessment instrument role differs throughout the study; it was considered at the early stages of the study as a way of seeing similar input level for the whole set of participants. It was used afterwards as a way of ensuring that all participants have the minimum prerequisite to pursue the experiment. Ensuring this minimum level of knowledge was not an option, actually at a point of time, the inability of the participants to understand the basics of math was of direct impact on hindering the whole experiment.

As seen in Chapter (5), the duration of the pre-assessment was altered twice. It was initially designed to make sure that subjects had almost the same knowledge prerequisite. Later, it has been lengthened to include a set of numerical questions that seem of no relevance to the objective itself. This change was recommended by the tutor. He had a concern about the weak numerical ability of participants in the basic numerical skills due to a past experience. He thought that a discrepancy of numerical ability across the two groups might affect the experiments results, regardless of their background. Hence, this set of numerical questions was added, to ensure the equivalence of platform skills across the experimental and control groups. The numerical and logical ability pre- assessment test aims to gauge the participant ability to perform the mathematical&/logical operations that could be needed while performing EVM calculations.

Finally, applying the numerical and logical pre-assessment in pilot II was seen as not necessary in light of the students' academic background and their university education level, so a decision was taken to keep the initial design so that not to lengthen the pre-assessment duration.

8.2.5 Post-Assessment Tool

During the early formative stages of the experiment, the post assessment has been changed to be more related to the topic being investigated using SD rather than the system thinking skills that will be gained from the applications of SD. This differentiates this study from other similar contributions. Studying the assessment instrument in similar researches that was previously discussed in chapter 2, section 2.5.2, proved that, there was focus on assessing the direct system thinking skills related to behaviour over time, and cause and effect, without relating these important skills to the topic taught.

8.3 Suggested Future Work

This section is divided into two different levels of suggestions, (i) suggestions related to improving the work in light of the factors that would have been of impact if considered within the current study, (ii) and suggestions for further development and research work.

8.3.1 The Experiment Design

The experience in delivering this experiment shows that it would be advised to have a more consolidated, in depth body of knowledge (mostly something like lecture notes or a text book) in order to give participants a more comprehensive overview of the concepts delivered. This will further assist participants to imbibe the theoretical delivered information and assist their knowledge retention ability.

These detailed lectures should be delivered in a gradual way in small chunks with feedback on every chunk. It is also highly recommended that the content should be developed to include more practical examples and case studies outlining the usage of EVM and its effect on project performance. This will aid participants to gain an in-depth understanding of the concepts and its practices, also it will help tutors who are interested to use this technique, and it will help developers who are looking for investigating further work in the same field.

8.3.2 The Pool of Participants

The number of participants is of direct impact on the validity of the study result. Having limited number of participants in this experiment for both groups, encourage engaging various supporting analysis with the statistical analysis, such as the qualitative analysis of the participants' textual answers. In order to reach wider pool of participants, a further recommendation is to try developing content based on a blended learning approach for the same current experiment with detailed design instructions that will secure the full engagements of the participants' from both groups. This will enable the tutor to have full access to a higher number of participants without hindering the quality of the experiment. The existence of solutions for online delivery of business simulations and predictive analysis like “forio.com” makes it easier to upload the existing models or its amendments and try it out on a wider segment of participants. Applying the blended approach will also help in reaching wider pool of participants, as this will allow for using the same instructor, hence; using different tutors won’t impact the experiment’s validity.

8.3.3 Retention Test

Learning is about the acquisition of knowledge and concurrently the retention of such knowledge for a while, and the ability to apply the previously acquired knowledge is another higher level of learning and understanding the topics taught.

As being said by Swezey, about the importance of enabling learners to apply and to transfer what they have learnt later on through their lives (Swezey, Llaneras, 1997). It is important to know how well the skills taught will endure after acquisition, and not only how the learners act during the learning process activities and assessment.

Having a kind of retention test, that could be applied after a period of time from the post assessment, and analysing the results of the same participants of the experiment would be of a great support and influence to the hypothesis of the study. It also gives strong evidence on the impact of SD learning based approach on achieving higher level of the knowledge retention.

8.3.4 Deeper Assessment Instrument

From the inconclusive quantitative results explained in section 6.2.2, it is recommended to enrich both the variety and number of questions. Also adding different types of questions to the post assessment instrument, for example the type of scaling questions, would allow for deeper level of results’ assessment like regression and functional analysis, which was not considered in the design of this instrument.

8.4 Research Issues

In reviewing the whole research methodology, and the way it impacted results, some of the issues reflected on the expected output of the research study that might be taken into consideration when taking this work forward.

8.4.1 The Detailed Instruction Design of the EVM Lesson

It was mentioned in Chapter (5), that during the execution of the first pilot, some of the participants started working on the SD models in a way that caused a further delay to the initial design of the experiment. Further detailed instructions should be given, that would help in keeping the participants in full engagement and with clear detailed steps to follow. What happened was due to the tutor engagement with other participants' software setup activities, and at the same time there was no guidance for the rest of the participants.

8.4.2 The Design of the Post Assessment Instrument

The study work proved that there was an improvement in the learning and the understanding of the Earned Value management lessons for the participants from the experimental group in comparison to the participants from the control group, which has been proved by both (i) quantitative analysis of their results in the post assessment and also from (ii) the qualitative analysis of the participants' elaboration and explanations to the answers in their post assessment exam. The fact that the significance of the results of this study is of a great dependence on the effectiveness of the post assessment, it would be of privilege, to enrich the post assessment instrument in a way that allows for having multiple set of questions per the same question type category. As further regression analysis can add up to the existing level of the analysis. The decision of designing the instrument tool was made to focus on the adaptable levels of questions only rather than enriching the number of questions of the same category. Although, the design considered the qualitative analysis of the subjects' answers to provide proven statistical differences of both group participants' results, it is important to consider increasing the reliability of the assessment instrument in future work in terms of wider scale of questions' types and numbers to increase the depth of the results and its analysis.

8.4.3 Challenging the Participants' Mindset

Participants from the experimental group had significant inhibitions when they were asked to experiment and try the different scenarios by hand. Those inhibitions wore off as they came along through the experiment. Providing the participants with a safe environment in which they felt comfortable to make mistakes and learning from different scenarios and outputs encouraged the participants to challenge themselves and dare to ask, try, observe, and give their own opinions and judgements. SD based lessons for Earned Value Management provides the participants from the experimental group, the ability to make beneficial analysis of mistakes and errors of judgment. This allowed for making mistakes and errors, which created a true learning experience and deepened the participants' analytical ability.

8.4.4 The Language of the Participants

The participants from both groups, found it very hard to express themselves in the exam sheets that was written in English. This significantly affected their ability to express their narrative views on questions asked. One major area that was affected in terms of depth was the analysis area. Some of the participants even resolved to writing in Arabic language to be able to express their views or answers, which is clear from their snapshot answers shown in Chapter (6) and clearly in the appendix of their scanned papers.

Some of the previously mentioned issues matched the tutor's feedback as in the following:

> *"Familiarity: For subjects from the experimental group, significant assimilation time was required for them to get more adapted into the simulation environment. Having no background in simulation; and being exposed first time to simulation software slightly impacted their ability to manipulate the models freely. This resulted in some inhibition which took some time to overcome."*

> *"Challenging the mind-set: Students had significant inhibitions when they were asked to experiment and try different scenarios by hand. Those inhibitions wore off as they came along as they were provided with a safe*

environment in which they felt comfortable making mistakes and learning from different outputs. SD and simulation provide one of the most important and breakthrough features in project management education; which is empowering the student to make beneficial analysis of mistakes and errors of judgment. This contributes to making mistakes and errors a true learning experience and deepens the student's analytical ability".

"Language: Students found it very hard to express themselves in the exam sheets in English. This significantly impacted their ability to express their narrative views on questions asked. One major area that was affected in terms of depth was the Analysis area. Some students even resolved to writing in Arabic to be able to express their views or answers".

8.5 Summary and Conclusion

It was proven that using system dynamics based learning in the area of Earned Value Management can provide an interactive visual learning environment, allowing for manipulating the system, and offer the ability to explore more of the scenarios of 'what-if', and practice the skill of 'know-how'.

The visualization of the relationships and the continuous reinforcement of system thinking skills were of an impact on the scores of experimental group versus the control group. Counting as a horizontal reinforcement of information and knowledge, the experimentation package aimed to constantly bombard the participant with systems varying in complexity and size to prompt his/her thinking approach in terms of systems thinking. It's worth mentioning that, the different models didn't add up to different learning skills, however; it acted as a brain-muscling activity to enhance the same set of skills related to the dynamic causal relation as an immersion experience of project management and EVM.

These features cannot be seen as a replica of offering graphs using spread sheets or Excel sheets; it was clearly shown through the comparison between the way of visualizing and exploring the different systems' behaviours versus having the other static graphs. Sometimes, there is an argument about the limited ability of spread sheets, which is due to the limited ability to design these spread sheets. However; let’s assume that, the validity of the proposition that it is difficult to implement the simple dynamic model using spread sheets due to participants’ limited awareness of the software. The question is; what would be the case with professionals, if they were given a rather complicated model of different dynamic variables and levels of linear and nonlinear equations, how would it be handled? and how will it address all of these complexity?.

Guidelines were given for tutors, researchers, and developers. Some of these guidelines are coming in light of the different nature of the participants’ community, as well as their different educational background, different language, their way of perceiving the idea of the research study, and the continuous exceptional political conditions occurred during the study duration in Egypt, that in many times affected the experiment participants’ commitment, and the delivery of the experiment, among other factors. With all of these cultural differences, the work still contributes to this research area as an empirical study.

Another conclusive point is related to the implications of using SD in a learning environment, (i) First SD on its own, is one of the powerful tools for systems with a specific set of features like systems that are characterized with causal dynamic relations, otherwise; this impact cannot be easily validated. (ii) Second the influence of SD on exploring and trying the dynamic causal relations that constitute the system concept was studied, as SD does not add to the amount of the new information of the topic of study, however; it reinforces practicing a set of skills that are needed to grasp the idea of causalities, relations, and dynamic behaviour. This is in a way could be related to exercising the brain muscles to digest more and more about the same set of this interacting world.

The output of using SD based teaching in project management was expected to be evident mainly in measuring the analysis of a certain context, but not necessarily with the questions that are measuring the direct concept of memorization.

At the end, this thesis has provided considerable support to the hypothesis of the research study, using a methodology of design, evaluate, implement, and assess, this was clear from (i) the overall results with a score of ($t=4.601$, $df=44$, $p<0.0005$) explained in section 6.2.1.1, (ii) the qualitative assessment of the participants' explanation detailed in section 6.2.3.

The set of guidelines and suggestions paved the way for future work that hopefully would benefit other researchers in the same field, and tutors who are looking for different ways of getting participants more engaged and challenged.

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