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USING SERIOUS GAMES TO TEACH MANUFACTURING CONCEPTS AND AN EVALUATION STUDY FROM TEACHERS' PERSPECTIVE

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ABSTRACT

An undoubted fact today for manufacturing industries is that they are looking for ways to transform their operations into a structure which allows them to be performing these operations coherent with sustainability aspect that is becoming more and more recognized every passing day. While this fact is becoming more significant as the time passes, the level of knowledge of the people who are initiators and performers of sustainability applications in manufacturing industries is started to be questioned. Accordingly, undergraduate engineers may be considered as the prospect executives of the future who will take responsibilities, and to be able to facilitate their learning about sustainable manufacturing by letting them transfer their knowledge in experience while they are still at university becomes essentially an area of research. It is said that currently traditional teaching and learning methods are not sufficient enough to attract today's students' attentions to engage them in manufacturing education therefore new fashioned approaches need to be focused on in order to prevent the shortcomings of traditional methods.

Learning with games, may have the answer to this growing need because of the engaging solutions they provide for students which facilitate their learning by letting them feel the experience and live the moments. Therefore serious games term which may be defined as having the computer game features to achieve a particular educational objective comes into prominence. Although games are considered to be having a favorable potential to facilitate learning, there is a lack of emprical evidence to support this argument. Accordingly the necessity of an evaluation study is identified to be able to consider an effectiveness of a serious game.

Given these facts and arguments, in this dissertation, first a literature review, that starts from broader terms and in the end focusing on sustainable manufacturing education, has been conducted to have an insight about the usability of game based applications in teaching sustainable manufacturing. As a result of the favorable results obtained, a serious game evaluation framework has been developed by analyzing and combining some features of existing frameworks and the evaluation sessions of Sustainable Global Manufacturing Serious Game have been conducted that is still being developed and currently considered to be one of the rare serious games directly focusing on sustainable manufacturing field. The evaluation study has been performed following a qualitative methodology with a total of nine teachers whose topic of interest is related to

sustainable manufacturing. The results demonstrated an indication of usability by teachers if the game works completely, and it revealed some redesign recommendations which needs to be taken into account by the designers of the game during its development phase.

1. INTRODUCTION

1.1. Statement of the Problem

In today's educational context, facilitating the learning process to the learner is an important topic and the debate about how this objective can be attained is an active area of research. The reason for this issue to be discussed is that traditional learning methods where learners are simply listening to their instructors or reading assignments are becoming outdated. Nowadays, learners can be considered as having the dynamism to perform anticipatory actions for achieving objectives. The use of technology, especially internet has a significant role in their lives by allowing them to have a greater flexibility to make a research for any data they need. They want to feel engaged in what they are being taught, to be a part of problem solving process by being able to apply their acquired knowledge in reality instead of just hearing a solution. If they see the results of their actions it becomes possible for them to judge themselves and as a result they can change/modify the behaviors and approaches they have. Therefore, researchers are addressing the applications of new teaching methods instructors may adapt into their teaching curricula which may allow them to be a guide for their students in their learning process instead of being an actor who just transmits information to their students.

The theory of learning is defined by Witteman (1997) as an adaptable change from the environment to inputs and in the educational field, cognitive learning is expressed as the most attractive one that results in managing and retaining information which can be applied into different scenarios. Kolb (1984) describes learning as a cycle which is initiated by experiencing, followed by reflection, conceptualization of knowledge and finally applying acquired knowledge in reality and also states that each person has a different learning style.

As it is stated, there are ongoing researches about how learning can be facilitated in the educational field and this issue continues to be a topic of interest. Accordingly, facilitation of learning by means of game applications is becoming a hot prospect. Prensky (2001) describes traditional education as a process where learning is not often motivational or engaging and he claims that game playing is in contrary to this approach because the process of game playing is engaging and he emphasizes on his argument that video games are the most engaging tool in the history. Oblinger (2006) states that in

a game environment, the previous knowledge of the players are reminded, problem solving is achieved, transfer of knowledge is possible and players learn from what they have performed thanks to the feedback mechanisms. The concept of serious games emerges following these definitions and they represent the computer/video games which have an educational goal beyond entertaining that contain government or corporate training, education, health, public policy and strategic communication objectives (Zyda, 2005).

Currently, the size of manufacturing industry is growing to expand and social, economical and environmental effects of this expansion is becoming more of an issue with the rise of the concept; sustainable manufacturing. Accordingly, the education of sustainable manufacturing in higher education becomes an important topic because a higher education institution is considered as a place where the future prospect professionals, decision makers are trained and these institutions have the responsibility to convert students into graduates who can make a change to create a sustainable society (Sibbel, 2009) As stated by Hunt et al., (2011) innovative learning programs and methods are required in order to maintain the approach on the world wide priority of educating the workforce. It is required to make alterations in the direction of engineering education Fenner et al., (2005). Taisch et al., (2010) pointed that educating engineers in an effective way is a novel research subject and its meaning is developing in the next years. Since sustainability objects are promising in the manufacturing area engineers have to obtain competences in order to face with them effectively (Cerinsek et al., 2011). It is essential to modify university engineering programs to meet sustainability prospect in manufacturing (Dolinsek et al., 2011) so that graduating engineers are able to be supporters for the execution of sustainable strategies and practices in their potential associations (Fenner et al., 2005). Therefore the idea of using game based learning applications, such as serious games in teaching manufacturing concepts to facilitate learning for the learners, emerges.

Accordingly, the first research objective of the present document is to determine whether serious games, in the context of sustainable manufacturing education, could replace traditional teaching models.

Evidence of games' potential is attracting the learning researchers even though there is an inadequate number of resources which evaluate the effectiveness of game applications (Rickard and Oblinger, 2003). Randy Hinrichs from Microsoft's Learning

Science and Technology Group states that students are capable of learning more effectively in simulated worlds by taking on different roles, viewpoints, purposes. De Freitas (2006) focuses on the results of the literature review stating that to have an effective learning with games players must be engaged, motivated, supported and interested in the game and pointed out that designers must provide an accurate balance of having an enjoyable game experience while accomplishing particular learning outcomes. Shute et al., (2011) lists the elements of a well-designed game as a one which contains problems to be solved; provides rules for engaging learners; has goals and achieves results and has feedback, as well as a good story telling. These elements are associated with a good instructional design. Whitton (2009) indicates that performing an evaluation study of a digital game is helpful to decide whether or not applying such a game facilitates the learning process while monitoring the development of learners. Taking into account the ideas of educators while evaluating a serious game application is also an important step. According to Hainey (2010), it is important to figure out what makes instructors decide to introduce a game based learning method into their teaching curricula as they have the authority to select the methodology that will be held while they will be teaching. Paloş and Maricutoiu (2006) indicate that teachers' only duty is not just to give information to their students, but the way they do it has an impact on their students. Additionally, their ideas and recommendations can be used as a strong evidence in identifying the weak points of a learning game application and add value to the redesigning phases. In accordance with the first objective, we aim to develop a serious game evaluation framework by means of searching the existing frameworks in the literature to be able to assess the effectiveness of a serious game.

The second objective of the document lies on the development of an evaluation framework to assess the effectiveness of a serious game application from the instructors' perspective.

2. RESEARCH METHODOLOGIES

2.1 Introduction

The objective of this section is to summarize the main objectives of our research and specifying the research questions. Then the selected research methodologies in order to achieve our objectives and to answer our research questions are pointed out.

2.2 Research Objectives

The primary objective in our research was to address the change in the needs of learners to facilitate their knowledge acquisition so that improved learning can occur, and to research and understand if learning with games such as deploying serious games, that have the features of video/computer games and have an educational objective, may be a useful new learning tool in sustainable manufacturing education. Because considering the expanding size of the manufacturing industry, sustainability issues come into prominence and it is believed that sustainable manufacturing education becomes vital for engineers who are the executives of the future and there exists a shortcoming in today's traditional teaching methods to teach sustainable manufacturing issues to them.

In our research, we may reach the generalization that game based learning applications are considered as useful, facilitates learning and are used in a variety of application areas. However, we agree with the views which indicate that not every instructional game is successful just because they are used in an educational context, so their assessments need to be conducted in order to be able to come to the conclusion and say that a game based learning application such as serious games achieves the facilitation of learning to learners. Instructors' views have a significant importance as well because they are the ones who can decide whether to use or not a game based learning application in their curricula. Accordingly, our secondary objective in this research is creating an evaluation framework to assess the effectiveness of a serious game from the point of view of instructors. For this purpose, developed framework is aimed to be used to evaluate a sample game that is currently being developed and named as Sustainable Global Manufacturing Serious Game in case it may be a useful tool to replace traditional methods. As a result of game evaluation study, it is also aimed to reach redesign recommendations that can contribute to the development phase of SGM serious game.

2.3 Research Questions

First: Do serious games have the potential to be used in sustainable manufacturing education?

Second: What are the existing evaluation frameworks in literature and how can effectiveness of a serious game be evaluated?

2.4 Selection of Research Methodologies

In this section, the selection of appropriate research methodologies to answer the research questions is identified including literature review searching criteria and the sources, explanation of survey instruments and their deployments. Before demonstrating the research methodologies that are selected to answer research questions, some definitions are discussed shortly as the following.

A methodology is made of interrelated methods that can be classified as qualitative and quantitative (Hainey, 2010). Quantitative research is constructed on the quantity or the amount measurement. It can be applied to hypothesis that can be expressed with quantities and data are analyzed in a systematic manner whereas qualitative research facilitates understanding of characteristics, procedures and experiences of a practice for researches and allows practitioners to share the success of the output of the research that is being done (Higgs, Horsfall and Grace, 2009). The most important difference between a quantitative and qualitative research is their flexibility (Mack et al., 2005). For example, in quantitative researches all participants are asked the same questions in the same way and the answers to these questions can be considered as closed ended. In contrary, qualitative researches allow more flexibility which means there may be an interaction between the researcher and the research participant because the questions which are asked are open ended questions that allows participants to respond freely in their own words instead of simply replying “yes” or “no”.

Three main methods for data collection can be specified in qualitative research and they can be listed as focus groups, direct observation and in-depth interviews. Among these three, the most used one method for data gathering is interviewing technique (Thomas and Hersen, 2010) which is a systematic way to collect data by interactive talking and listening. Types of interviews can be listed as structured, semi structured and unstructured interviews. Semi-structured interviews can be considered as the most

common qualitative research methods and they are used often in qualitative analysis (Alvesson and Deetz, 2000). They are performed with the guidance of predefined questions in specific themes and require the interaction between interviewee and the interviewer so that it can be possible to gather particular information from the responses (Sandy and Dumay, 2011). An important strength of semi structured interviews is that researchers can have instant reactions to inquire a deeper information from the participants about the examined situation using interviews as research instruments (Kajornboon, 2004).

Hainey (2010) lists the methodologies used in researches with their advantages and disadvantages and constructs the following table 1.

Methodology	**Main characteristics**	**Advantages**	**Disadvantages**
Experiments	Variables are studied in an active way in a controlled environment.	Irrelevant factors can be removed and resulting in influenced behaviors so factors of interest can be isolated to draw conclusions about the causes of behavior.	There might be ethical issues related with the examination of variables. A synthetic environment can be created in which people may behave differently.
Quasi-experiments	The design represents an experiment, but variables are not manipulated. There is no randomization and participants are categorized by researchers based on characteristics that existed before	Some irrelevant factors can be removed but this is less than in a true experiment. Although root of the behavior is not known, expected relationships can be identified.	The affirmation of cause and effect relationships cannot occur since variables which have the important potential are not controlled.
Correlational Studies	Already existing variables are controlled without being controlled.	Behavior can be examined naturally because complicating variables are not removed and expected behavior patterns can be observed.	Determination of variables which cause the behaviors to happen is impossible.

Surveys, tests and Questionnaires	Opinions, behavioral reports and self reported knowledge are gathered from the ones who respond.	A considerable amount of different data can easily be gathered and it can be compared with the response patterns of other groups that are studied.	It is not possible to have identification of cause and effect relationships, and also to tell how accurate the knowledge and behavior is reported.
Case Studies	A single person, a small group of people is studied deeply so as to get a lot of information from them.	Each person can be studied individually in his complicated nature and their particular characteristics can be considered to understand a behavior.	The group may not be resembling the people in general and making generalizations can be difficult.
Observational Research	Behaviors are examined naturally. Mostly there is no interference.	Life and behavior can be examined in full complication.	Identifying why people behave in some particular ways is difficult because there exists a lot of influential factors in the natural world
Longitudinal Research	Behaviors are examined during a long time period.	It is possible to observe behavior changes occurring at a particular time.	The study can take a long time in which the behaviors of people can change.
Archival Research	Present records, articles, and available information are used to find answers to the research questions even if the accessed information is collected for another purpose.	Historical information tracking, the use of multiple sources are possible.	It is not possible to know the accuracy of the information or if there is any information omitted. Maybe the focus of the information that is reached is on a different purpose.
Ethnography	Researcher himself involves deeply in the group that is being examined.	Evidences with high details can be collected.	Engaging feature of the research requires a lot of time, it is time consuming.
Meta-analysis	Results of a	The reviewer can specify the trends	Huge amount of

	research within a given research area analyzed quantitatively.	occurring in the literature, statistical tests become more powerful which leads for reviewers paying more attention reading the papers.	time is required as identification and coding of studies are required.
Content analysis	Uninterrupted observations are performed by means of analyzing the traces of actions.	Researchers are allowed to study behavior through a number of circumstances or situations that can be difficult.	Chosen participants may not be sensitive about the matter which is being recorded.

Table 1: Major methodologies used in research design (Hainey, 2010)

2.4.1 Research Methodologies Selected to Answer Research Questions

First: Do serious games have the potential to be used in sustainable manufacturing education?

The methodology for this research question is selected as archival research and a literature review is conducted by using the following search terminology: “learning”, “video games”, “serious games”, “game based learning”, “manufacturing”, “sustainability”, “sustainable manufacturing”, “life cycle assessment”, “workplace learning”, “education”, “training”, and “teaching”

The literature review is performed by using a variety of available online sources and also the databases which are including mainly: Emerald, Science Direct, Springer journal, Springer Books, Science Online, Science Direct, IEEE, Technology Research Database, NTIS, Science Citation Index, Compendex, OPAC, IGI Global and ELSEVIER.

Second: What are the existing evaluation frameworks in literature and how can effectiveness of a serious game be evaluated?

The methodologies selected to answer these research question can be split into two parts, first part consists of developing a theoretical framework for evaluation of serious games. Second part consists of a sample evaluation study where developed framework is used to evaluate Sustainable Global Manufacturing (SGM) serious game that is currently being developed and yields redesign recommendations for SGM serious game's designers.

The research methodology selected for the first part of this research question is an archival research and it aims to find existing evaluation frameworks and the perspectives contained in the literature for evaluating game based learn applications and creation of a serious game evaluation framework to assess the effectiveness of them. As it is done for the first research question by searching for the search terms; "learning outcomes", "evaluation", "computer games", "serious games", "educational games", "game features", "effective training" through a number of online resources and in databases including Emerald, Science Direct, Springer journal, Springer Books, Science Online, Science Direct, IEEE, Technology Research Database, NTIS, Science Citation Index, Compendex, OPAC, IGI Global and ELSEVIER

The research methodology selected for the second part of this research question is the survey/questionnaire methodology. It is aimed to conduct a qualitative survey with a number of teachers in which a questionnaire is prepared grounded on the serious game evaluation framework. Accordingly, an evaluation session for assessing the effectiveness of Sustainable Global Manufacturing (SGM) serious game as a learning method is conducted with the participation of teachers who are considered to be having the power to decide using a new teaching method in a learning environment. Evaluation sessions are expected to be held in a semi structured interview format individually with each of the teachers who accept to take part in the study.

3. LITERATURE REVIEW

3.1 Sustainable Manufacturing and Its Education

3.1.1 Environmental Aspects of Manufacturing

In our world, many natural resources are scarce to meet the demands of all humanity and the following generations but they continue to be highly demanded in today's growing industrial economies. Manufacturing industries may be considered among the ones which have the highest impact on the consumption of these finite resources and consequently the environmental impacts manufacturing industries create are becoming argumentative.

While raw materials are transformed into products in manufacturing, environmental wastes and emissions are concurrently produced from the use of energy and materials in manufacturing processes (Yuan et al., 2012). Manufacturing industries comprise considerable part of global consumption of reserves and production of waste (Cerinsek et al., 2011). When we look global energy consumption of manufacturing industries, it increased by 61% from 1971 to 2004 and comprise almost one third of today's universal energy consumption (OECD, 2010). According to International Energy Agency report published in 2011, 5870.9 million tons of CO_2 emission was produced by the manufacturing industries and construction in 2009. A detailed CO_2 emission by sector in 2009 is shown in table 2. Yuan et al., (2012) states that manufacturing wastes and emissions are the root causes of environmental problems and economical issues because of the exertion connected to environmental emission alleviation, control and retrieval inside and outside the manufacturing system. Since manufacturing industry has major environmental impacts regarding to emissions and wastes, sustainable production and development catch the huge attention of industries in current years.

million tonnes of CO_2

	Total CO_2 emissions from fuel combustion	Electricity and heat production	Other energy industry own use **	Manufacturing industries and construction	Transport	*of which: road*	Other sectors	*of which: residential*
World ***	**28 999.4**	**11 827.1**	**1 464.1**	**5 870.9**	**6 543.8**	**4 876.6**	**3 293.4**	**1 875.0**
Annex I Parties	*13 011.7*	*5 323.2*	*654.9*	*1 849.2*	*3 339.1*	*2 897.4*	*1 845.3*	*1 078.9*
Annex II Parties	*10 236.0*	*3 942.0*	*541.8*	*1 363.4*	*2 911.9*	*2 578.5*	*1 476.9*	*816.6*
North America	*5 715.8*	*2 292.5*	*322.9*	*636.1*	*1 771.9*	*1 529.9*	*692.4*	*362.8*
Europe	*3 001.2*	*985.3*	*154.2*	*432.6*	*824.0*	*768.3*	*605.1*	*387.9*
Asia Oceania	*1 519.0*	*664.3*	*64.7*	*294.7*	*316.0*	*280.4*	*179.4*	*65.9*
Annex I EIT	*2 517.0*	*1 279.9*	*101.9*	*444.9*	*382.0*	*279.4*	*308.3*	*224.0*
Non-Annex I Parties	*14 972.0*	*6 503.9*	*809.2*	*4 021.7*	*2 189.0*	*1 979.2*	*1 448.1*	*796.2*
Annex I Kyoto Parties	*7 497.2*	*3 000.7*	*384.0*	*1 252.3*	*1 673.9*	*1 451.0*	*1 186.3*	*709.2*
Non-OECD Total	**15 939.0**	**7 102.6**	**807.5**	**4 244.1**	**2 213.5**	**1 916.0**	**1 571.2**	**913.0**
OECD Total	**12 044.7**	**4 724.5**	**656.6**	**1 626.8**	**3 314.7**	**2 960.5**	**1 722.2**	**962.1**
Canada	520.7	102.2	65.7	91.7	157.6	127.1	103.6	38.5
Chile	64.9	22.6	3.3	13.3	20.5	17.9	5.2	3.4
Mexico	399.7	118.8	50.5	51.8	147.3	143.5	31.3	18.5
United States	5 195.0	2 190.2	257.2	544.4	1 614.3	1 402.8	588.8	324.3
OECD Americas	**6 180.4**	**2 433.8**	**376.7**	**701.2**	**1 939.6**	**1 691.4**	**729.0**	**384.7**
Australia	394.9	222.5	21.7	49.8	82.4	70.1	18.4	8.0
Israel	64.6	38.2	2.2	1.2	17.0	17.0	6.0	2.7
Japan	1 092.9	434.4	41.3	238.8	220.1	198.2	158.2	57.4
Korea	515.5	251.1	31.8	88.7	85.2	79.9	58.7	31.4
New Zealand	31.3	7.3	1.7	6.1	13.5	12.1	2.8	0.6
OECD Asia Oceania	**2 099.1**	**953.6**	**98.8**	**384.5**	**418.2**	**377.3**	**244.0**	**100.0**
Austria	63.4	13.8	6.0	12.1	21.7	20.7	9.7	7.2
Belgium	100.7	21.5	4.9	21.8	26.4	25.8	26.1	17.1
Czech Republic	109.8	59.4	2.5	18.9	17.7	16.9	11.4	6.9
Denmark	46.8	22.0	2.4	3.8	13.1	12.0	5.5	2.9
Estonia	14.7	11.0	0.1	0.9	2.1	2.0	0.6	0.2
Finland	55.0	25.3	3.5	9.0	12.2	11.2	5.0	2.1
France	354.3	52.3	16.0	57.6	123.9	118.0	104.5	58.9
Germany	750.2	308.7	25.2	101.9	148.7	141.0	165.7	113.8
Greece	90.2	44.5	3.3	7.3	24.6	20.8	10.5	7.3
Hungary	48.2	15.3	1.6	5.6	12.8	12.5	13.0	8.3
Iceland	2.0	0.0	-	0.6	0.9	0.8	0.5	0.0
Ireland	39.5	13.0	0.5	3.9	12.1	11.8	10.0	6.9
Italy	389.3	130.8	16.4	50.2	110.8	104.5	81.2	50.3
Luxembourg	10.0	1.2	-	0.9	6.1	6.1	1.8	1.2
Netherlands	176.1	57.2	10.4	39.0	32.8	32.0	36.6	17.6
Norway	37.3	2.4	11.4	6.6	13.5	9.9	3.4	0.5
Poland	286.8	152.3	7.0	32.7	44.5	43.2	50.2	31.7
Portugal	53.1	19.9	2.4	7.2	18.9	17.7	4.8	2.0
Slovak Republic	33.2	8.3	4.5	7.6	6.0	5.0	6.7	3.1
Slovenia	15.2	6.0	0.0	2.1	5.1	5.0	2.1	1.1
Spain	283.4	87.0	17.5	47.3	100.5	88.5	31.2	17.9
Sweden	41.7	8.1	2.7	6.8	21.1	20.2	3.0	0.4
Switzerland	42.4	2.9	1.0	5.8	17.1	16.8	15.6	10.4
Turkey	256.3	99.4	11.2	40.8	44.8	39.0	60.1	38.3
United Kingdom	465.8	174.7	30.6	50.8	119.7	110.5	90.0	71.2
OECD Europe	**3 765.2**	**1 337.0**	**181.1**	**541.0**	**956.9**	**891.9**	**749.2**	**477.4**
European Union - 27	*3 576.8*	*1 305.8*	*165.5*	*509.2*	*912.9*	*855.6*	*683.5*	*436.1*

Table 2: CO_2 emissions for the same sectors. (Retrieved from International Energy Agency report published in 2011)

3.1.2 Sustainability Concept and Reasons to Adopt Sustainability

According to Bruntland Commission Report, United Nations, (1987) sustainability is defined as "meeting the needs of the current generation without compromising the ability of future generations to meet their needs." Cerinsek et al., (2011) states that other definitions of sustainability comprise "living within the limits of what the environment can provide, understanding the many interconnections between economy, society and the environment, and more equal distribution of resources and opportunities." According to Pfeffer (2010) there is an increasing public and business interest in developing sustainable associations. Sustainability that is described fairly as an attempt to save natural resources and prevent waste in operations by Pfeffer (2010), is known as

a significant notion by modern associations for continuing to exist in the ambitious world (Bevilacqua et al., 2007). Those associations are pushed to accept practices that are planned to preserve environment safety and decrease energy consumption (Senthilkumaran et al., 2001).

Sustainability is also associated with the capacity of a company to "maximize resource efficiency for ensuring clean and green atmosphere (Vinodh et al., 2010)." Process and product design subjects are combined with production planning and monitor to recognize, count, evaluate and manage the stream of environmental waste among fundamental aim of decreasing environmental impact by green system (Azzone and Noci, 1996). Green system seeks to exploit resource efficiency intended for the manufacturing of sustainable parts. Sustainability is the vital connection among issues similar to production and product design exercises and the environmental factors (Rusinko, 2007).

When we look from universal point of view to understand reasons to go for sustainability it is seen that sustainable strategy is the best option (Langenwalter, 2006). Some examples to support this view are provided below.

- If China spends the equal quantity of oil per person like United States, the whole existing world production of 83 million barrels a day would be expended. Although it is not seen doubling by the most hopeful forecasts of oil production, some professionals believe that our oil production is extremely close to maximum production.

- If all the people on the world consumed the same level of resources like U.S, the demand would be equal to resources of five planets. Although Western Europeans have the similar life standards they consume only half the resources per person as Americans.
- World's population is getting larger; it was doubled since 1960. However the quantity of arable land is getting reduced.

Sustainability that is an innovative practice is changing quickly from a fringe. Most Fortune 500 companies have already adopted sustainability and assigned a sustainability manager. Behind 1980s, companies who adopt sustainability gain lasting competitive

benefits among their industries. It will push the stragglers to adopt sustainability (Langenwalter, 2006).

According to Langenwalter (2006) when a company decides to execute sustainability it is seen that sustainability can start in a single department of this company and then it extends to other ones. Sustainability is desired from many people essentially because sustainability is mostly asking the correct questions in order to assessing society, company profits and the environment. Langenwalter (2006) gives an example to sustainability from U.S. Army. Sustainability has been accepted as a tactical initiative by the U.S. Army. However this initiative did not begin at the top stage. It started with a middle stage civil servant that was interested in reading books. Then this servant starts inviting his friends in order to create a book group. In that group they had a chance to read and discuss a book monthly. Members of this group informed others about their activities and share their books with them. One of these books was taken by a commander of a fort landlocked in a crowded area that was continually disapproved by the public for its impression on the environment. After he read that book he tested a pilot sustainability program. Once the results were observed he and the public were both satisfied. Then he shared those results with another commander who had similar studies. Therefore the concept started expanding. It can be said that sustainability performs in associations of whole volumes, profit and non-profit. It can be performed in stores, offices, manufacturing companies, hospital, government, transportation companies, schools and universities at whole stages.

Bleek (2005) states powerful observations about the importance of Life cycle assessment in sustainable development. He approved that LCA would be vital while shifting to more sustainable lifestyles and products. According to him the firms that are not able to improve and sell sustainable products might be eliminated from the market in the next 20 years.

3.1.3 Life Cycle Assessment

According to European Environment Agency (1997) life cycle assessment that can be called as “life cycle analysis”, life cycle approach”, and “cradle to grave analysis” or “Ecobalance” acts as a quickly promising family of tools and techniques created to assist in environmental management and extended period in sustainable development. Life cycle assessment is found functional both as a conceptual framework and a collection of practical tools. It can be said that both views are true depending on the

context. From the point of scientists and engineers “Life cycle thinking” is able to be found as an enormous spur to their inspiration and talent to observe the extensive aspects of a problem.

What is the role of the LCA in sustainable development?

Currently sustainable development is put on the worldwide agendas. According to Bleek (2005) LCA would be vital while shifting towards more sustainable lifestyles and products. Therefore it can be said that LCA is getting a growing need.

European Environment Agency (1997) indicates that LCA needs quick developments in eco efficiency as a priority. In other words, it requires fast developments to use energy and materials received from nature in an efficient way and reduce waste. Therefore cleaner technology will be created. When we examine the life cycle of a product it is seen that it includes assembling, shipping, using activities of that product. The usual life cycle is composed of a sequence of phases starting from removal of raw materials and continuing through processing, manufacturing, packaging and waste disposal.

Throughout the studies of them companies and practitioners were asked about the most significant functions for life cycle assessment. In accordance with the answers of sustainability survey new product development was the trendiest reply. With respect to this report corporate strategy is the second valuable area for the business respondents. In addition LCA presents the view of the corporation’s liability for the entire life cycle, supporting the development of strategy review. Practitioners and researches both believe that potential of life cycle thinking is brilliant. Clift (1996) who is a professor in the claims that “it is key that life cycle thinking be fostered throughout organizations, and be adopted as part and parcel of the organization’s philosophy, mission and day to day operations. This makes it essential that lifecycle thinking also be applied to corporate educational processes (Hauschild, 2005).”

What is a product’s life cycle?

Alting et al., (2000) states that the purpose of a lifecycle assessment is the completion of the product and a specific function which is described by what is required to complete this function. In fact life cycle assessment is most frequently seen as an environmental assessment of products with a purpose of the whole processes that are required for the product in order to run during its life cycle from cradle to grave.

According to Hauschild (2005) life cycle assessment was grown as an analytical tool in order to assist measuring the environmental effects from products or services. To facilitate performing of a product's function it has to be improved, manufactured, delivered to its consumers and also kept in good condition throughout usage. Resources have to be removed and transferred into materials, elements. Once the product is not able to perform its aim any more it has to be reprocessed in other ways. A physical connection among these activities is developed by transportation processes. Environmental impacts are produced because of these supportive activities. If the analysis concentrates on the life cycle of the product the effect of the entire environmental impacts are obtained. The life cycle of the product is shown in a universal form in figure 1.

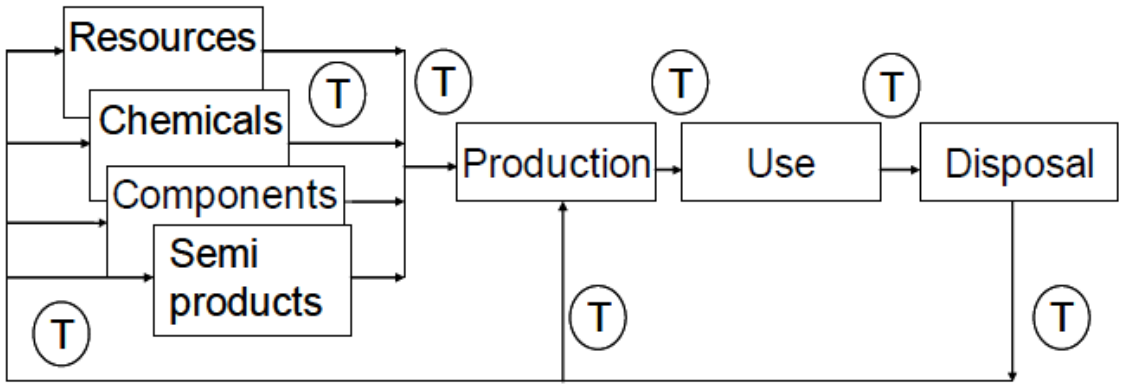

Figure 1: The life cycle of a product. Transportation processes (circumscribed T) form a physical link between processes and life cycle stages. (Retrieved from Hauschild, 2005)

When a company makes a decision numerous actors are affected on the life cycle of its products. The requirements of the company are supplied by these actors. The company is managing and servicing its products or paying attention to the products while they are discarded (Hauschild, 2005).

Phases of Life Cycle Assessment

As shown in figure 2 the life cycle assessment framework is composed of four phases: Goal and scope definitions, Inventory analysis, Impact assessment and Interpretation.

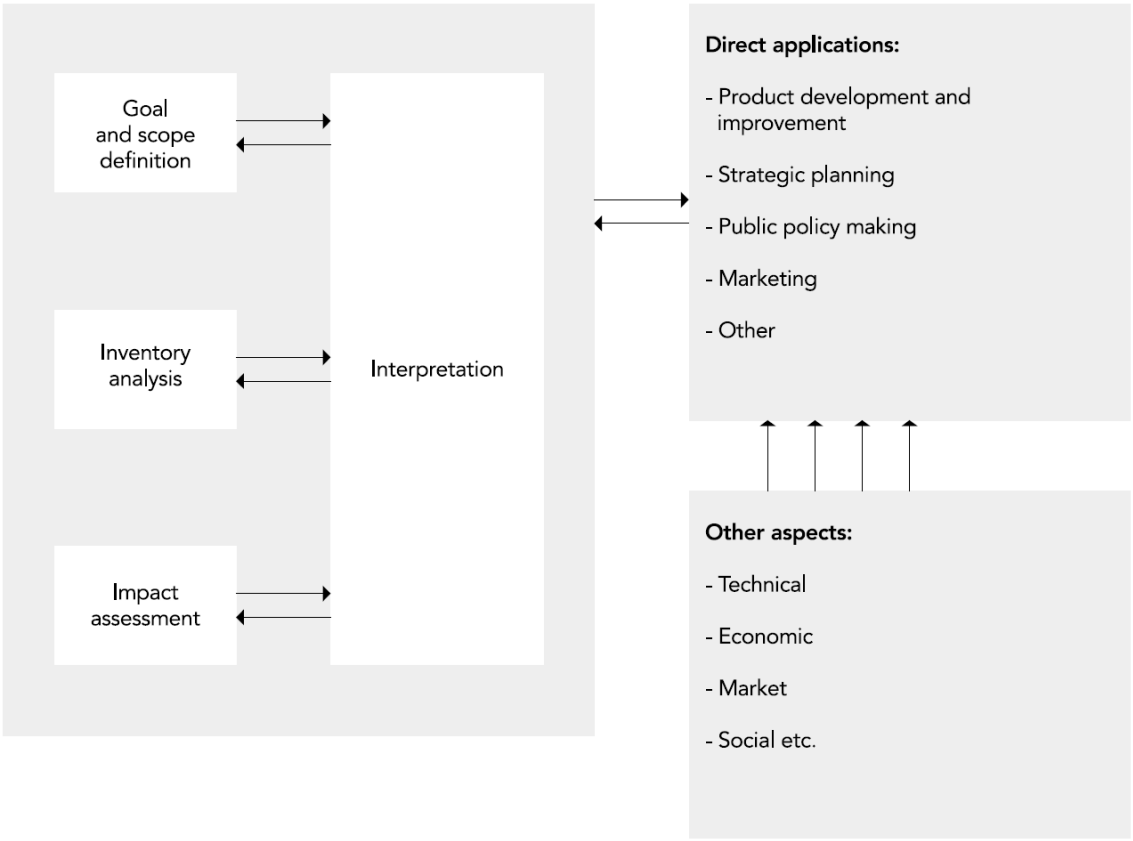

Figure 2: Life cycle assessment framework - phases of an LCA (ISO, 1997a). (Retrieved from European Environment Agency, 1997)

The double arrows among the phases specify the interactive nature of LCA. For instance while performing the impact assessment it may be clear that inventory analysis has to be improved.

Goal and scope definition

According to European Environment Agency (1997) goal and scope definition that is the first phase of the life cycle assessment includes these major subjects: goal, scope, functional unit, system boundaries, data quality and critical review process. Since the definition of the goal and scope has a great effect on the outcome of the LCA it is known as a critical part of a LCA. Alting et al., (2000) states that the goal definition explains the aim of the study and decision procedure to which it may supply input for environmental information.

Inventory analysis

Inventory analysis that is the second phase of the life cycle assessment includes these major issues: data collection, refining system boundaries, calculation, validation of data,

relating data to the specific system and allocation. Generally the collection of the data is built on mass balances for the process more than an extended period of time. It is crucial to be sure that the average functioning of the process is represented by the data (Alting et al., 2000).

Impact assessment

Impact assessment that is the third phase of the life cycle assessment includes these major issues: category definition, classification, characterization and valuation/weighting. According to Heijungs and Hofstetter (1996) the impact assessment is able to be defined as "quantitative and/or qualitative process to characterize and assess the effects of the environmental interventions.

Interpretation

Interpretation that is the fourth phase of the life cycle assessment includes these major issues: identification of significant environmental issues, evaluation, conclusion and recommendation. According to Alting et al., (2000) in this phase the outcomes are interpreted beside the lines of the defined goal and in conformity with the restrictions described by the study. Sensitivity analyses are executed and the result of the interpretation gives suggestions to the decision makers.

In order to cover company's own processes and other activities its reliability is expanded throughout the mission for sustainability. Therefore the reliability is expanded up-stream in the product chain and also down-stream in order to contain company's influence on its products' performance throughout their end of life treatment. If a company has a purpose to perform in a sustainable way it is required to consider entire supply chain. The solutions to environmental problems in a product life cycle generate new problems in a different place of life cycle. The holistic system's point of view allows the company reveals the problem shifting in case it is used in life cycle assessment. The companies which desire to improve their activities in a sustainable manner they see LCA as a precious decision support tool. Nowadays, LCA is used for concentrating and evaluation of alternatives in a product development, for certification of environmental impacts in marketing, and for decision support in environmental organization. This tool is used for examination of societal system alternatives such as

examination of waste management systems (Harrison et al., 2001; Dalemo et al., 2000; Sonesson et al., 1997).

3.1.4 Sustainable Manufacturing

According to WCSD (2010)[1] Sustainable Manufacturing is one of the divisions of a comprehensive concept of sustainable development. Sustainable manufacturing appeared in the early 1980's as an answer to raised responsiveness and concern regarding to environmental and social impact of economic improvement of business. In sustainable development environmental issues are put together with imperatives of economic improvement to meet the urgent demands of the people nowadays by considering the ambitions of the future generations. Nevertheless the scope of the sustainable development is increased to cover the opinions of justice and interdependence between both generations and countries. Goodland (2002) stated that sustainability can be split into human, social, economic and environmental sustainability. The three main dimensions of the sustainability are shown in figure 3.

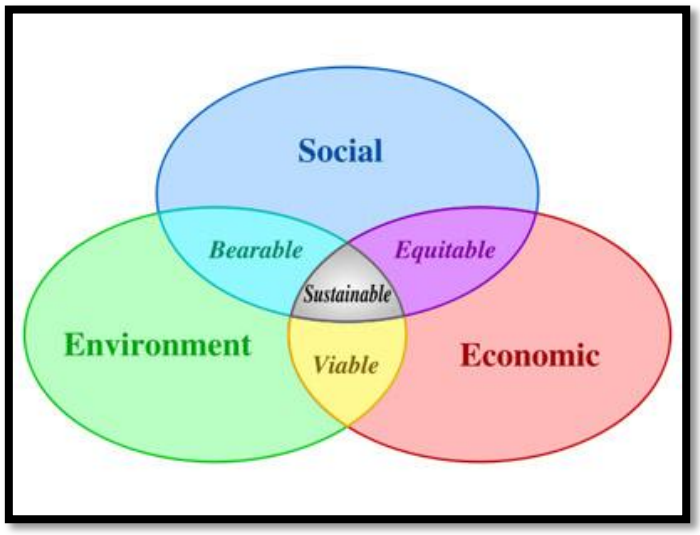

Figure 3:Main dimensions of sustainability (Retrieved from the presentation of Prof. Prabhu in 2012)

The **Environmental Sustainability** is seen as a capability to maintain quality of the physical environment. It is related to issues such as utilization of renewable and non renewable natural stocks, conservation of quality of water, air and soil, energy efficiency and stability of eco system.

The **Economic Sustainability** is related to sustainable human development and growth, which is guiding to increased quality of life, employment, social and economic justice.

[1] World Centre for Sustainable Development.

In addition improvements and utilization of technologies, knowledge and innovations are needed as resource of cost optimization.

The **Social Sustainability** is the link among development and present social norms. It involves allocation of wealth and services among generations. When an activity conforms to social norms it can be socially sustainable.

Hauschild et al., (2005) states that more strategically oriented companies look towards sustainability with its focus not only on ecoefficiency (economic and environmental impacts) but also social impacts and the ethical aspects of their operations. According to Leahu and Aluas (2010) sustainable manufacturing enlarged the whole processes and decisions of the companies into wider social and natural environments in which companies work. The US Department of Commerce describes sustainable manufacturing as the development of manufacturing processes that minimize negative environmental impacts, save energy and natural sources.

Leahu and Aluas (2010) states that since sustainable manufacturing deals with three dimensions of sustainability: environment, economy and society it is more inclusive and systematic than green, eco manufacturing and clean manufacturing. According to WCSD (2010) sustainable manufacturing employs a more holistic method which considers whole life cycle phases from pre manufacturing, manufacturing and usage through post use. The purpose of this holistic view of sustainable manufacturing is accepting sustainable principles across the entire manufacturing life cycle and defining whole inputs and outputs for continues development. These phases are distributed across the whole supply chain with diverse partners that are organizing activities at each of these phases. Therefore numerous players in the manufacturing process have to accept sustainable principles to meet higher production standards.

Accordingly, companies upgrade their manufacturing processes and products which minimize environmental impacts by conserving social and economic advantages. Also consumers expect to receive products that are made in a sustainable way (MIT Sloan Management Review 2011). Since there is a growing trend for consumers to be offered sustainable products and services by enterprises the challenge of manufacturing companies are raised to meet sustainability (Duin et al., 2012). Who aware the fact of staying competitive in the market they do develop and execute sustainable manufacturing techniques and tools (Joung et al., 2012).

3.1.5 Education of Sustainable Manufacturing and Current Limitations

According to Cerinsek et al., (2011) education for sustainable development has been promoted after the outcomes of UN Earth Summit in Rio de Janeiro at 1992. It is recognized as a topic of universal significance. Therefore it has become a main concern in national policy documents. It is also confirmed that education is crucial for supporting sustainable development subject. Fokkema et al., (2005) states that "each engineer has a responsibility to the society and should have an awareness of possible ethical, social, environmental, aesthetic, and economic implications of their work and to act accordingly." According to Wulf and Fischer (2002) world is becoming more complicated so engineers have to be grateful more than ever the human aspects of technology, be responsive to educational variety and also be aware how to communicate successfully. Holmberg et al., (2008) says that sustainability has to be a part of their everyday thinking when engineers assist to sustainable development.

On the other hand engineers should cope with emerging issues in a competitive environment. Since sustainability objects are promising in the manufacturing area engineers have to obtain competences in order to face with them effectively. There are two criteria that are required to be reached by engineers. First one is converting their knowledge into complex and life like conditions. Second one is accomplishment of knowledge outcomes in a short time period (Cerinsek et al., 2011). Azapagic et al., (2005) says in their world-wide research that the quantity of the knowledge and awareness of sustainable development between engineers is not reasonable and there is a major knowledge gap. However a hopeful outcome from their research is that students are aware of the fact that knowledge on sustainable development is crucial for engineers even though they regularly experience problems while trying to connect the theory of sustainable development with engineering practice.

Manufacturing enterprises want to hire engineers who are capable to work in hard conditions and who can adopt his/her knowledge and experience in order to adopt emerging sustainability related trends. Therefore manufacturing enterprises can stay competitive (Dolinsek et al., 2011).

It is essential to modify university engineering programs to meet the demands of sustainability prospect in manufacturing (Dolinsek et al., 2011). According to O'Sullivan et al., (2009) while opening new classes regarding to sustainability in the engineering program is just "half the battle". The other part is how to educate new

engineers to make them work in complex environments. Taisch et al., (2010) pointed that educating engineers in an effective way is a novel research subject and its meaning is developing in the next years. Because of that reason universities should provide innovative learning environments to their students so that their learning and competence achievement about sustainability will be facilitated (Sampson et al., 2008; Wert et al., 2004; Martin et al., 2005 and Petersen et al., 2010). For example a Guideline Competency Standards for Sustainability was introduced by the Australian Manufacturing Skills Council in 2006 (Dolinsek et al., 2011). This guide was created to show teaching and learning of appreciated competences in the area of sustainable manufacturing in official job training. The Institution of Civil Engineers (ICE) set up a Task Group in order execute sustainability rules directly into education, training and professional improvement Fenner et al., (2005).

As a result, development and execution of new learning techniques and environments become more crucial. It is required to make alterations in the direction of engineering education. Therefore graduating engineers may be able to be supporters for the execution of sustainable strategies and practices in their potential associations (Fenner et al., 2005). Additionally, graduating engineers have to work successfully in complex environments in order to converge potential sustainability needs and objectives in manufacturing (Cerinsek et al., 2011). For this reason, students require innovative, responsive and engaging learning environments which assist their learning to reach a required stage to be able to start a professional career (Wert et al., 2004). In order to facilitate the creation of mentioned learning environments for students in sustainable manufacturing education, we believe that the use of video games can be a complementary tool for the problems occurring currently, such as the difficulties they have to experience their knowledge in real life applications. Therefore in the next chapter of our study we will mention about the theories of learning, what is learning with digital games and what features they have, and how they may be used as a supplementary tool in sustainable manufacturing education.

3.2 Towards Learning with Serious Games

3.2.1 Theories of Learning

Learning, from a general point of view, basically, is a function which is based on desires (Furth, 1987). Illeris (2003) describes learning as the capability of human beings which developed via evolution and lets them understand more complicated issues compared to the other living things and it is the most important part for species in their effort for continuing to exist. Witteman (1997) defines the theory of learning as an adaptable change from the environment to inputs. In the education field, cognitive learning is considered as the one which attracts the most attention and it can be expressed as choosing, clarifying and placing the information (Enciso, 2001). Thus, it can be stated that in cognitive learning, individuals perform the learning activity in different ways such as listening, touching, watching, practicing all of which leads to managing information so that retaining information is possible and the retained information can be applied into different situations.

Jean Piaget was the first psychologist who conducted an organized cognitive development study and his work gave inspiration to many researchers who came after him. Piaget's cognitive theory was composed of 3 basic components; "Schemas", "Assimilation, Equilibrium, and Accommodation (Processes that enable the transition from one stage to another)" and "Stages of Development" (McLeod, 2009), in his study which is constructed with children Piaget claimed that children are able to think in many different ways than adults do. According to McLeod (2009) these stages can be described as the following. "Schema" is a unit of knowledge which is related to a particular concept in the world. A child reaches to the state of equilibrium, a cognitive balance, when his present schema allows him create connections about what he knows and what is happening around him. Piaget describes cognitive development as an adjustment process which is realized through assimilation, accommodation and equilibrium. Assimilation stands for the use of an existing schema while looking at new conditions or entities. Accommodation occurs when an existing schema needs to be modified because it may not work (a state of disequilibrium) in some circumstances and between the previous two elements an equilibrium state is reached (disequilibrium is over by updating the schema) when children are capable of interacting new information using their schemas. Piaget described the stages of development under four main subtitles and these sub-stages are summarized and explained by McLeod (2010) as the

following. The first stage is named as sensorimotor and covers the years from birth up to two years during which a fast intellectual development takes place. Infants begin to construct a reality around them because they are believed to be having reflex movements and intuitive systems. In this phase, children adjust their reflexes to the real world and they show a high egocentrism which means the child cannot understand different arguments rather than his own present point of view. The second stage is named as preoperational and covers the ages from 2 until 7. In this stage, children can mentally create connections to events and objects and employ them. At the end of this stage (around 7 years old), Piaget concluded that children give up being egocentric and perceive also other points of view. The third stage is named as concrete operational and children are considered to be in this stage between the ages 7-11. In concrete operational stage, the logic of children become more developed, their thoughts become more operational, their egocentrism decreases and their ability to perform conservation tasks are improved. The fourth and the last stage is named as formal operational and begins at about 11 years old. Children become adolescents and they begin evaluation ideas in their brains, they become capable of thinking individually and draw conclusions in a reasonable way. Kolb (1984) came up with the experiential learning theory and stated that there were significant differences between his theory and Piaget's cognitive and adult development theory. Piaget represents adult development as a unilinear process (Hickcox, 1990), in contrast to this experiential learning theory represents human development as a multilinear process (Kolb, 1984). It is composed of two stages which are a cycle of learning with 4 phases and four distinct styles of learning (McLeod, 2010). In this cycle, learning process starts with a Concrete Experience (CE) where a learner actively participates in a learning activity, then secondly comes the Reflective Observation (RO) of the learner on the experience (contradictions between the experience and the knowledge). The third phase is Abstract Conceptualization (AC) during which new ideas can be generated as a result of the personal reflection on the experience or a present abstract concept can be changed. The fourth and last phase is the Active Experimentation during which the learner applies his acquired knowledge in real situations to get results. Based on these 4 phased learning cycle, Kolb learning theory defines four separate learning styles and states that each person has his own learning style which can be affected by social environment, educational background, or the essential cognitive structure of an individual (McLeod, 2010). Kolb (1984) places four

learning cycles on two different axis, and states that learning preference occurs by one variable's combination with one of the variables placed in the opposite axis. One of the axis is composed of "Active Experimentation and Reflective Observation" whereas the other one is composed of "Concrete Experience and Abstract Conceptualization" on the opposite sides. Learning styles are named as diverging, assimilating, converging, accommodating. Figure 4 shows the relationship among the learning cycles and the learning styles.

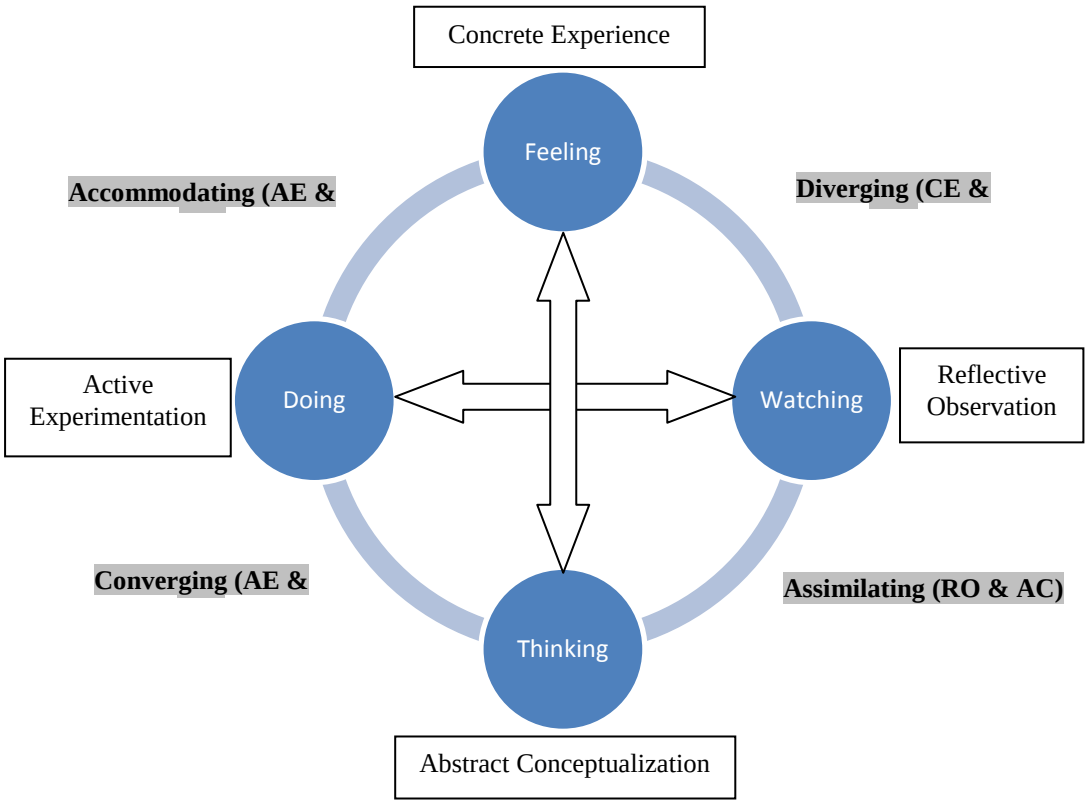

Figure 4: Experiential Learning Cycles and Learning Styles (Kolb, 1984)

McLeod (2010) explains these four learning styles as the following

Diverging (CE & RO): People who have this learning style are sensitive and they are capable of looking at situations from different point of views. They are interested in people and they would rather observing something instead of performing it and intend to collect information to solve problems. Divergers are good at generating ideas and they have the preference to work in groups, to listen to the others, and to receive feedback.

Assimilating (RO & AC): This learning style can be described as a precise and a reasonable attitude. People who have an assimilating learning style have the need of clarifications instead of practical opportunities. They are less focused on people and become more interested in ideas and abstract concepts. Thus, people who have this learning style have the preference to read, to have lectures, and to have time so that they can figure out things.

Converging (AE & AC): People with a converging learning style are more likely to solve problems by using their knowledge to find solutions to specific practical situations. Technical tasks interest them more and they become less concerned about people and multipersonal relations. Convergers like to experience new ideas, simulate them and work with real life applications.

Accommodating (AE & CE): This learning style requires the involvement of active participation and counts on perception rather than logic. People who have this learning style follow and use the analysis of other people and they prefer to have practical experiences. New challenges and experiences, and accomplishing things are attractive for them. They follow their inner voice and perform according to that instead of logical analysis. This learning style is the most widespread one.

To summarize, in this part, the definitions and theories of learning are provided. A major part of the studies which are performed point out that Kolb's experiential learning theory is functional in five academic areas; accounting and business education, the helping professions, postsecondary education, and teacher education; and educators will be assisted with an understanding and application of Kolb's learning cycle to organize their curriculum to concentrate on their learning environments (Hickcox, 1990).

3.2.2 A New Approach – Learning With Games

The popularity of digital games is increasing every day and games are becoming a part of peoples' daily lives. According to the study was done by Strategy Analytics[2] in 2009 the value of global video game software market is $46.5 billion and it is believed that by 2013 global game software revenues will reach $64.9 billion. The study of Entertainment Software Association (2012) which demonstrates the results for American household states that a gamer has been playing games for an average of 12 years, and adult players have been playing for an average of 14 years; males with an

[2] Market intelligence firm.

average of 16 years game play and females with an average of 12 years game play. There are many reasons for playing games, in a survey at 2001, Entertainment Software Association (ESA) demonstrated four reasons for playing games,

- 87% of most frequent computer and video game players declared that the first reason for them to play games is because they are fun
- 72% said that games are challenging
- 42% stated that they consider games as an interactive social experience with their friends and family
- and 36% said that games have a lot of entertainment value for the money.

Also considering these facts mentioned above this, the use of games can be regarded as an effective new tool in teaching environments. However, there are differences between games for education and games for entertainment. Summit (2006) claims that developers of educational games must focus on first the desired learning outcome, and then design the game to achieve that objective. Hays (2005) defines the following definition of a game,

"A game is an artificially constructed, competitive activity with a specific goal, a set of rules and constraints that is located in a specific context (Hays, 2005)"

Hays (2005) states that a game is not a reality, it is an activity that is built to reflect the some segments of reality in which a competitive environment is created for players by challenging them to reach an objective. He also explains that all games cannot be used for teaching and most of the games intend to be created for enjoyment, so a game which is designed for teaching must support specific learning outcomes and must integrate with the instructional program in a reasonable way.

Another usual definition of games from the literature has been made by Salen and Zimmerman (2004) who described games as systems in which players are connected to an artificial conflict that is identified by rules, resulting in a measurable result. According to Gee (2003) computer games are compatible with Kolb's (1984) experiential learning cycle because learners must explore the virtual environments created in the games, react back on the situations and generate ideas about what is going on and then act according to that so that they can explore the virtual world and see the results of the actions they had. Oxland (2004) describes computer games defined by

rules and limits, a representation of the real world, context, objectives with challenges and a playable game environment. De Freitas (2006) identifies computer based learning games (also called serious games which will be explained in detail in the following section) as applications which contain the features of video and computer games so that they can create engaging and immersive learning experiences to accomplish predefined learning objectives, outcomes and experiences.

Prensky (2001) describes traditional education as a process where learning is not often motivational or engaging and he claims that game playing is in contrary to this approach because the process of game playing is engaging and he emphasizes on his argument that video games are the most engaging tool in the history. He summarizes these motivating elements as the following; games are *fun* and gives pleasure, they have *rules* which provides us a structure, they have *goals* to motivate us, they are *interactive* which gives us the feeling of doing, they are *adaptive* which provides us flow, they contain *outcomes* and *feedback* which results in **learning,** they have *win states* which results in the state of being fulfilled, they have *challenges* which creates adrenaline, they have *problem solving* which inspires creativity, they have *interactivity* which leads us to integrate in a social group and they have *characters and stories* that create emotions.

According to Prensky (2001), there are five levels in which learning occurs by means of video games and computer games. He describes these levels as the following;

Learning How; in this level a person can learn how to do things in the created virtual world so that he can actualize those behaviors also in the real life. Because in games, learners do not simply learn the procedures of doing something but they repeat these actions repetitively which results in making learning reach the state of being internalized and becoming a second life.

Learning What; before the arrival of computer and video games, it was common to learn of the rules of a game before playing it. This issue is not the same for computer games, in a computer game's learning environment the player learns what to do in a particular game context, which means they learn about the rules of the game environment and what they can do or cannot do in it.

Learning Why; this third level of learning is described as players learn why they do something and they know more about the strategy of the game as they keep on playing.

Learning Where; according to Prensky (2001) at this level a player learns about the game world and the values it represents, and the most effective way for transmission of the *Where* can be considered as immersion. As much as someone gets the feeling of more connected to something, he learns more about it instinctively.

Learning When and Whether; this is the last level of learning where a deep learning occurs. It is the level in which players make moral based and moral decisions about if they are doing something bad or wrong. Players learn what to do and when to do things in real life which they learn from games.

Oblinger (2006) remarks some important points from the literature stating that game play has the potential to be an effective learning tool not only because of being fun, but also for being immersive, for making the player make decisions, for making them have clear goals and for requiring an involvement in a social network. He summarizes that games are often social environments and the social and cultural impacts of the games contain the meaning of a game and its value. She continues explaining about the research phase which takes in place in the game play saying that a player who enters the game environment evokes the prior knowledge he/she has, decides what is needed so that he/she can apply it to new situations. Problem solving as well is accomplished by means of games because games include collective actions through different fields of practice which make players use these information and techniques to achieve success. Finally she mentions that games provide the capability of creating links between existing learning and a particular situation so that transfer of learning can be performed, and she points out the experiential features of games stating that for each action the player takes, there is a response and a fast feedback so that the players are able to learn from the results they get from the game play. Whitton (2009) defines one of the benefits of digital games computers are capable of offering interaction and feedback which is vital for experiential learning cycle and for all learning process. According to the model of game based learning introduced by Garris et al., (2002), game based learning occurs in a recursive loop where it is important that essential game characteristics are combined with the instructional content which come together with behavior changes, interaction with others, getting the results of actions performed thus resulting in specified learning outcomes. Debriefing has a tremendous contribution and considered as essential for achieving learning outcomes as it is shown in figure 5.

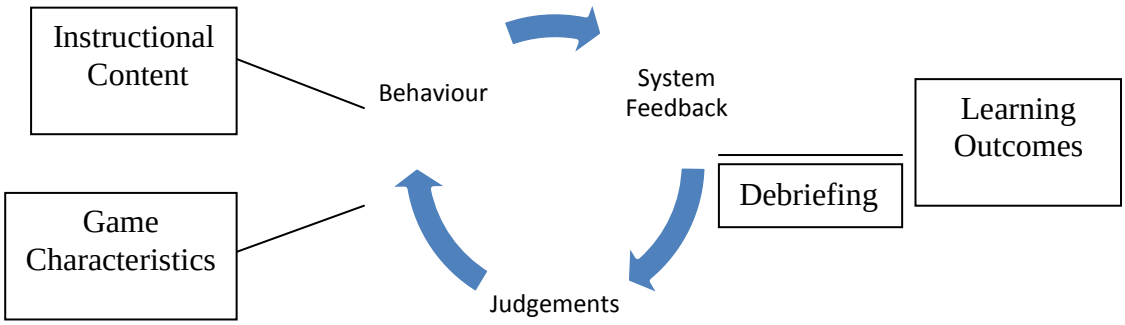

Figure 5: Model of Game Based Learning (Garris et al., 2002)

3.2.2.1 Empirical Evidence on Learning with Games

While the attitudes of educational researchers are generally positive for the use of instructional games in educational area, De Freitas (2006) and Wouters et al., (2009) indicate that there is a lack of empirical evidence in the literature to support the potential of instructional games.

Hainey (2010) summarizes the studies of Randel, Morris, Wetzel and Whitehill (1992) who conducts their study by analyzing 68 studies and comparing simulation and gaming approach with traditional instruction methods considering the student performances. The results were as the following;

- %56 of the studies showed no difference, %32 of the studies showed a difference favoring the use of simulation and games, %7 of the studies favored simulation and games but indicating that control was unquestionable, and 5% of studies favored the use of traditional methods.
- Regarding the retaining things in mind, simulation and games generated more retention in comparison with traditional methods.
- There were a number of 14 studies regarding the interest, and the results demonstrated that 86% of the studies indicated a higher interest in games and simulations towards traditional methods.

Hays (2005) conducted his study reviewing 31 theoretical articles, 26 review articles and 48 articles that presents empirical data about the effectiveness of instructional games resulting in 5 foremost conclusions;

- There exists a fragmented empirical research on the effectiveness of instructional games which include research on different tasks, age groups and

types of games, and the literature contains a lot of vague terms with plague methodological mistakes.

- In spite of the fact that there is an evidence of effective learning in different tasks for a various number of learners, it does not indicate to use a game for a particular instructional objective. The effectiveness of a game in an area for a group of learners should not be generalized considering another area of a game and another group of learners.
- No evidence exists that indicates that games are the preferred method for all instructional aspects.
- Debriefing and feedback should be included in the games so that learners can understand what happens in game and how they support instructional objectives.
- Learners should be provided with the instructional support rather than the requirements of the game so that instructional effectiveness of the game can be increased for the learner.

In conclusion, the future of learning with games, in other words game based learning will be a positive prospect and the power of games for learning should not be under estimated. Shaffer et al., (2005) indicates the virtual worlds created in games are a powerful tool because with them, it is possible to improve situated understanding. It must be remembered that, as Prensky (2001) declares, in 2025, there will not be any actor of educational systems such as students, teachers, supervisors- who have not played computer games in their lives. For this reasons, a new concept called serious games will be introduced in the next section of our study.

3.2.3 Serious Games

The term, serious games, stands for the computer/video games which are used for beyond of entertaining goal in education. Serious games may belong to any category and they are being considered as a way of edutainment and they are accepted as e-Learning methodologies (Thoben et al., 2005). De Freitas (2006) explains serious games as applications which contain the attributes of computer games that are used to create immersive and engaging learning experiences to achieve particular learning objectives, results and experiences. Duin et al, (2008) consider serious gaming as an efficient method to mediate skills and competencies and state that computer games are capable of not only making the learner improve his/her hard skills such as understanding the way

how complicated systems work, but also improving soft skills such as teamwork and communication in cultural diverse contexts and they state that serious games are being accepted as a learning tool for the upcoming generation which address the limitations of the previous tools which came before. Neill (2009) defines a game as a structured activity which has rules, goals, challenges and interactivity and a serious game as a game that has a serious business objective. He indicates that a serious game immerses the learner in a virtual environment in which they are free to make mistakes, they can look for help, and they can build up their own experience and it is a secure and cost effective method of completing tasks. During playing serious games, learners have the possibility to apply their acquired knowledge and make decisions while having feedbacks about what/how they are doing. Michael and Chen (2005) describes the concept serious games as a game which is designed to achieve more than just entertainment whereas Zyda (2005) gives the following definition; serious games are a mental challenge which is played with a computer complying with precise rules that uses entertainment for government or corporate training, education, health, public policy and strategic communication objectives. Serious games are designed as virtual environments which plainly have the intention of education or training with two key attributes; being educative and immersive (Poplin, 2011). As a result of the research Mitchell and Smith (2001) conducts, to have a successful serious game, the general composition of the game and provided instructions must be easy to understand so that the time required for understanding the rules of the game will be minimized. Johannesson et al., (2007) labels the term serious games as games which are used for training, advertising, simulation or education which can be run on personal computers and video game consoles. Corti (2006) considers game based learning and serious games as the same and according to him game based learning & serious games is about leveraging the strength of computer games to connect learners to accomplish a particular objective, for instance acquiring and developing new knowledge and skills. Johannesson et al., (2007) summarizes the differences between entertainment games and serious games as it is in table 3;

	Entertainment Games	Serious Games
Task vs. Rich Experience	Experiences are richer.	Focus is on problem solving
Focus	Main focus is to have fun.	Serious Games focus on important elements of learning.
Simulations	Simulation processes are simplified.	There is the necessity of assumptions for practicable simulations.
Communication	There is often a perfect communication.	A natural communication should be reflected (It may not be always perfect)

Table 3: Differences between entertainment and serious games (Adapted from Johannesson et al., 2007)

3.2.3.1 Application Areas and Some Examples of Serious Games

Serious games can be applied in a wide range of areas and it is possible to categorize them in many different ways. According to the Serious Game Classification online web site serious game markets are classified as in the following table and the number of games exist under each category in their database is illustrated in table 4;

Categories	Number of Games	Categories	Number of Games
Entertainment	1621	Culture & Art	97
State&Governement	75	Ecology	250
Military & Defence	45	Politics	74
Healthcare	236	Media	59
Education	1430	Advertising	658
Corporate	143	Scientific Research	62
Religious	69		

Table 4: List of Serious Game Categories and Number of Game Results in Each Category (Retrieved from http://serious.gameclassification.com)

In their study Johannesson et al., (2007) adopted the classification which Michael and Chen (2006) introduced. They classified serious game markets as; military games, government games, educational games, corporate games, healthcare games, and political, religious and art games; and a brief summary of some of these categories are like the following;

Military Games

The military's history of using games for training dates back to a long time ago. The first serious game designed for military is named as Army Battlezone and released in 1980. The most known serious games application "America's Army" is released in 2002 as for free unlike the other video games and by 2004 America's Army was downloaded more than 17 million times, created a community of 4 million registered players and the number of players increased 100 000 by every month Michael and Chen (2006), and according to Grossman (2005) it was a huge success for giving a solution to some of the problems which American army encounters such as reaching and employing new voluntary soldiers. Michael and Chen (2006) states that from the military point of view, video game playing generally results in improvements in hand-eye coordination, in multitask ability and in working in a team with the minimum use of communication.

Government Games

In the study of Johannesson et al., (2007) governmental games are described to be having concerned about crisis management, such as how to deal with terrorist attacks, disease outburst, health care management system problems, city planning, traffic control, fire fighting, defensive training which are dangerous, impracticable, or very expensive in performing real life.

Healthcare Games

There are plenty of serious game examples in healthcare sector and some of the examples of games which are applied in healthcare sector and illustrated in the literature can be shown as the following;

- A physical fitness game named *Dance Revolution* (De Maria, 2006) which can make physical exercise seem to be more enjoyable by combining the elements of video games and physical activities (Michael and Chen, 2006).

- Dental Implant Training Simulation from BreakAway Games[3] is created to teach dental school students and professionals in the aspects of diagnosis protocol and performing dental implant actions in a realistic, virtual and 3D environment to be able to increase learning outcomes in the fields of diagnostics, decision making and treatment protocols.
- Pulse from BreakAway Games[4] is the first immersive virtual learning environment where training health care professionals in clinical skills are possible. It provides the opportunity for both civilian and military health care professionals practice in case they need to be responding better which can be encountered in disastrous situations.
- Video games can be used for cognitive functioning exercises as well, such as memory practices, improvement of analytical and strategic skills and so on (Mitchell and Smith, 2004)
- Healthcare games can provide a Control mechanism with a biofeedback equipment to teach individuals control psychological and emotional conditions in a more efficient way, these feedbacks can be created by means of sensors which are measuring heart rate and/or skin conductance (Michael and Chen 2006).
- Packy & Marlon game, from the pharmaceutical field is used at homes, clinic waiting rooms, hospitals and diabetes summer camps and the studies concluded that children and teenagers with diabetes who had this game available to play decreased their emergency and urgent care visits by 77 percent (Corti, 2006).

Business and Management Games

Games are being used since many years for teaching business and management skills (Hays, 2005). According to the survey Faria (1989) conducted with training managers, companies and business schools about the use of games in their applications, %54.7 managers who gave an answer stated that they are using simulation games in their programs, the additional results also demonstrated the fact that more than 5000 firms used these business games and 1700 four year business schools made use of games in their programs. Some common features that management games share were identified in Hays (2005) as the following;

[3] www.breakawaygames.com
[4] www.breakawaygames.com

- A feedback mechanism existed based on the results' of the players' actions.
- The environment was represented in reasonable or mathematical relations some of which are considered as rules by the players and some of them showed up by the time during game play.
- Interactions between players and the environment were allowed and players were able to take on the roles of different managers so that they would be able to learn how they differed.
- An easy aspect of reality was provided to players so that they could focus on the fields they were learning.

Some examples of these games are like the following;

- Virtual-U is a serious game which is designed to make real administrators, deans, university donors understand the management issues of a university. Playing in an open ended mode is possible in the game in which players are enabled to model their university and they try to make it survive as much as possible. Virtual U campuses can be built up to 15 departments, and with a number of 500 professors teaching up to 10000 students. The player can construct programs to create funds to improve variety in university, and the player can make adjustments with the salaries of professors, funding of researches and any other variable to keep every department satisfied[5].
- Better Business Game is developed by British Telecom in telecommunication field which is about managing social and environmental issues in the business by giving the player the role of a CEO (Corti, 2006).
- PixeLearning's retail game aims to promote careers in retail industry and also stimulates the skill development for a retail staff (Corti, 2006).
- In 2008, Hilton Hotels integrated Ultimate Team Play role playing game in their training programs developed by Virtual Heroes which makes employees put in the situations where they must decide correctly to make a hotel customer happy[6].
- LearningBeans ® game, which has been developed by Pixel Learning in manufacturing area, offers its players to play through a detailed scenario considering high volume manufacturing and it contains sales, marketing, human resources, finance, production, distribution and exports planning in which

[5] www.gamespot.com
[6] www.fastcompany.com

learners are capable of understanding the relationships between all dimensions of the business (Corti, 2006).

- In energy/utility sector, British Gas developed a game which is built on an entertainment game engine to demonstrate the importance of customer communication and analytical problem solving for the field engineers (Corti, 2006).
- It's a Deal is a serious game, supported by the General Foundation of University of Alicante, which uses a simulated experience that increases the awareness of its target users who are mostly business English learners about the cultural rules, the rules that apply the British culture and practice of these rules which are performed in business environments. It demonstrates impact of the culture on an individual's linguistic behavior (Victoria and Marian, 2011).

As it is mentioned in this section, games are being used widely in various areas to facilitate learning. Their immersive and engaging environments, challenging structures, feedback providing mechanisms, interactive communication features, conducive nature for decision making-problem solving which let learners experience their knowledge facilitates the occurrence of learning. Accordingly, we believe that using serious games in their curricula may help instructors while teaching manufacturing concepts. Therefore, the next section of our study addresses the use of serious games in manufacturing education.

3.2.4 Serious Games for Manufacturing Education

Significant changes occur lately in training and labor market education area and the concentration changes from education and teaching towards learning – competence development (Illeris, 2003). Hughey and Musnug (1997) describe training as a process which requires personal involvement, engagement and experiential achievements. They state that training involves learning and competences are more essential than knowledge to represent actual strengths. Whitton (2009) lists the critical points of adult learning theory which he referred to the study of Knowles (1998) as the following;

- Adults need clear purposes in a learning activity to be able to be motivated and spend time and energy on it.

- Adults need to have their own control in the learning process and to take responsibility for what they have done which leads to a learner centered learning style where students are more independent.
- Learning activities have to consider that learners might have different types of backgrounds so they have to be designed in a way that this differentiation can be managed.
- Adults are open to learning when they have the chance which enables them to apply a skill or knowledge into real world situations. It helps preserving skills and knowledge.
- Adults learn best when they use learning activities to reach the outcomes of what they want to succeed.

Hughey and Musnug (1997) say that companies are realizing that learning is an effort which continues lifelong and activities such as employee trainings can have a positive impact on job satisfaction rate, productivity and profitability. Goldenberg (2006) indicates the results in an UK research which demonstrate that manufacturing firms which spend more on personnel training achieve 47% more productivity compared to the ones which spend less and in the services sector this productivity increase reach up to %13.

Squire (2005) states that traditional models of instruction are not working well in the new economy and he claims that new models of learning experiences need to be capable of responding the needs of industry at 21st century referring to the following table 5.

INDUSTRIAL AGE		INFORMATION AGE
Standardization	…..	Customization
Centralized control	…..	Autonomy with accountability
Adversarial relationships	…..	Cooperative relationships
Autocratic decision making	…..	Shared decision making
Compliance	…..	Initiative
Conformity	…..	Diversity
One-way communications	…..	Networking
Compartmentalization	…..	Holism
Parts-oriented	…..	Process-oriented
Teacher as "King"	…..	Learner (customer) as "King"

Table 5:Changes in Global Economies (Retrieved from Squire, 2005)

The Future of Learning and Development report (2009) reflects the results of a survey which has been conducted with leaders such as directors, managers, vice presidents,

CEOs from a wide variety of industries (i.e. technology, retail, education, industrial products, etc.). According to the results of the survey 85% of the respondents believe that future learning will be much more collaborative and in-classroom courses will be motivated less on "preach and teach" format but more on the experiential and interactive format of learning. Immersive virtual environments enable learners (players) taking part in new worlds by occupying them with roles which would be unreachable by them if it were not for those virtual environments which allow them to think, act and talk in new styles while experiencing this new world instead of just depending on words and symbols (Oblinger, 2006). Most recent improvements in the area of Technology Enhanced Learning (TEL) are able to assist this objective significantly. For instance serious games, simulations and other experiential learning methods provide innovative methods of learning and achievement of skills. This kind of atmospheres are able to assist engineers in connection of the theory and training of work related competences and possible usage of competences in numerous circumstances (Cerinsek et al., 2011).

Duin et al., (2007) described manufacturing systems as huge, complicated and expensive to operate and in this complicated environment, it is not so easy to transfer experience to younger staff except letting them work and experience it, and they agree with Schwesig et al., (2005) and Thoben et al., (2005) stating that the mediation of soft skills can be achieved by means of simulation games which represent serious games. Therefore Duin et al., (2007) reaches to the assumption that such kind of games are an applicable way of mediating experience when a virtual environment created in the game represents the accurate reality.

McLean et al., (2005) analyzes that if video games technology can be used in manufacturing applications and reaches the conclusion that manufacturing research, training and testing can take advantage of video gaming technology. His statement is consistent with the serious games concept that is applications of computer games which can be applied both for educating and training simultaneously (Annetta et al., 2006).

There exist some ongoing projects of serious games in manufacturing field which are listed on Games and Learning Alliance (GALA) web site (www.galanoe.eu). The following table 6 indicates the names and descriptions of the projects and descriptions which are retrieved from GALA web site;

Name	Description	Website
PRIME	Considering the existence of a limited time frame, and the need to maintain the business dynamics, there is a need to develop new competences in strategic manufacturing in the work environment. This need is tackled in this project.	http://www.alfamicro.pt/prime/project/overview.htm#main
TARGET	TARGET addresses the research, analysis and development of a Technology Enhanced Leaning as it enhances the competence acquisition of workers in innovation and project management.	http://www.reachyourtarget.org/
iLearn2Main	Through the use of VET training, personnel become more qualified and employable hence the ultimate production is considerably improved, as well as the total cost efficiency of the enterprise.	http://www.ilearn2main.eu/
inTime	Revises the fostering of delivery reliability by a system of rewards according to delivery performance.	http://data.fir.de/projektseiten/intime/
MyCar	Designed for the automotive industry, this project deals with such a degree of customisation that it will lead to the customer being an active part in the assembly processes.	http://www.mycar-project.eu/
LeanPPD	Innovation and customisation play an important role in the ultimate quality of a product. By developing a model based on lean thinking that considers the entire product life cycle, the project aims to attain a higher quality, more sustainable and affordable product.	http://www.leanppd.org/
GEM	This project aims at the creation of an international framework for a master's degree curriculum in manufacturing strategy that truly reflects the needs of the manufacturing industry.	http://www.sintef.no/static/tl/projects/gem/
STELLAR	Stands for Sustaining Technology Enhanced Learning at a LARge scale and intends to unify the TEL community in order to contribute,	http://www.stellarnet.eu/

	synergise and extend the work towards TEL research in Europe.	
ATC21S	ATC21S tackles the problem of the current curricula and its inability to prepare students to live and work in a society that has a great deal of information. Digital literacy, thus, becomes a skill of paramount importance in today's workers formation.	http://atc21s.org/
GREAT	The aim of this project is to use innovative methodologies in learning and training in a way that trainers, teachers, and training providers will be capable of improving their performance. This is planned to be facilitated by means of augmenting their creativity and with the use game based applications.	http://www.projectgreat.eu/
KNOW-FACT	In this project, "teaching factory" concept is mentioned as a promising concept. It expands the process of learning by committing each year a laboratory project to students about a particular manufacturing course.	http://www.knowfact-project.eu/
ActionPlan	The first one of the two activities exist in this project is to develop the vision Information and Communication Technology in European manufacturing industry in short, medium and long time horizons. The second activity is the development and validation of a concept for industrial learning.	http://www.actionplant-project.eu/

Table 6: Dissemination Channels of Manufacturing Serious Games (www.galanoe.eu)

3.2.4.1 Serious Games for Teaching Sustainable Manufacturing

The importance of manufacturing education, which can enable companies create a difference from the other ones, is increasing day by day so that they can survive more in highly competitive markets. Accordingly, the importance of the way manufacturing activities are being performed becoming more crucial and the education of the sustainability concept in manufacturing come into prominence. Scholz and Reiter et al.,

(2002) and Hague et al., (2010) state that serious games can be extremely successful while teaching sustainability to engineers because they facilitate the acquisition of not only technical skills, but also soft skills like collaboration, creativity and communication. "Wicked problems" are undertaken by serious games and they are described by a high level of complexity, uncertainty and conflict which are typically not adopted by other learning techniques (Cerinsek et al., 2011). There are some companies who have already started considering serious gaming as a part of their future strategic plans. For example, Volvo Group stated on their official website[7] that by 2020 all major Volvo Group plants will be tested virtually before making changes in the real life so that an optimization of work plants in terms of sustainability and competitiveness can be achieved.

Although sustainability education is becoming important and serious games applications are being considered among the new tools which can facilitate learning about this topic, Hauge et al., (2008) indicates that there is not a serious game which is to support sustainability issues in manufacturing. Sustainable Global Manufacturing serious game developed in TARGET (Transformative, Adaptive, Responsive and engaging EnvironmenT) Platform is emerged to fill in this gap in sustainable manufacturing education. It recognizes sustainable manufacturing as a promising area where new competences are needed to assist the new manufacturing models and technologies. The SGM serious game seeks to improve an innovative Technology Enhanced Learning (TEL) platform that offers learners a responsive atmosphere where quick competence improvements and distribution of experiences within the field of sustainable manufacturing are enabled. According to Cerinsek et al., (2011) SGM serious game by itself is able to be used successfully in engineering education in order to encourage future engineers' fast competence improvement within the course of sustainable manufacturing. Learners can fundamentally experience complicated environments by enjoying the platform. It aims to offer unique learning experiences which are not feasible to be acquired through other types of learning methods which currently exist. The focus is on allowing learners to apply the knowledge "in practice" which they acquainted "in theory". The SGM serious game will give a chance to learners to practice and learn about sustainable manufacturing fields that are presently underspecified in

[7] www.volvogroup.com

usual courses such as holistic and systems thinking, decision making for sustainability, interdisciplinary cooperation, communication skills.

3.3 Evaluation of Serious Games

3.3.1 Importance of the Evaluation of Serious Games Applications

The interest to use instructional games in learning has been increased lately (Prensky, 2001). According to Greenblat (1981) instructional games can increase the motivation and interest of the learners more than classroom based lectures thanks to their practiced and moving features. Kirchner (2006) states that video games facilitate active learning and learning occurs while players have the chance to find solutions by actively participating. Modern theories of effective learning suggest that learning is most effective when it is active, experiential, situated, problem-based and provides immediate feedback (Boyle, Connolly and Hainey, 2011). Although using serious games while teaching are considered to be a useful tool, according to Becker (2006) it is not comprehensible how people precisely learn with serious games, how the learning is able to be more effective and what learning support is successful in what circumstances. De Freitas (2006) and Wouters et al., (2009) indicate that there is a lack of empirical evidence in the literature to support the potential of instructional games. In other words, there is a short of systematic research on this issue Wideman et al., (2007), therefore evaluating the effectiveness of these educational games becomes more argumentative. It is stated by Whitton (2010) that, in addition to being a means of evaluating learners' progress, carrying out an assessment is also useful in order to determine whether employing a digital game for learning has been successful. Evaluation of digital games for learning becomes crucial for two reasons; the first one is that, without evaluation there will not be any measurement of effectiveness which shows that if the game is successful or not. And secondly, evaluation enables figuring out what worked well and what did not so that there can be possible improvements in the game package in the future (Whitton, 2010). To summarize, it is believed that game based learning applications need to be evaluated for the following reasons;

- To be able to use serious games more efficiently and more widespread.
- To be able to make game users more unprejudiced aiming to increase their acceptance.

- To be able to provide more useful, enhanced learning outcomes whereas increasing learning efficiency.
- To be able to contribute to the serious game development process.

Accordingly, in our study we aim to develop a theoretical framework that may help instructors, who are the ones to select which tool to use in their teaching curricula, for evaluating the effectiveness of instructional games.

3.3.1.1 Existing Serious Games Evaluation Frameworks

Searching in literature determines a number of frameworks for evaluating the effectiveness of serious games. In our study, 4 evaluation frameworks coming from literature are identified. Explanations are provided below and list of the frameworks are shown in table 7 addressing those which are used in previous studies in assessing the effectiveness of serious games and also those which are focused on instructors' point of view as our focus group in this study to assess the effectiveness of serious games.

Study	Framework
de Frietas and Oliver (2006)	Four Dimensional Framework
Kirkpatrick, (1994)	Kirkpatrick's four levels for evaluating training
Hainey (2010)	Game Based Learning
Cheng Tzu and Chung Hung (2011)	Serious Educational Games taxonomy

Table 7: Existing Evaluation Frameworks

The first one is, "Kirkpatrick's Four Levels for Evaluating Training" where Kirkpatrick described four levels to evaluate training programs (Kirkpatrick, 1994). Although Kirkpatrick's framework is mostly best known for evaluating corporate training, Schumann, Anderson, Scott and Lawton (2001) states that his framework would be useful in assessing the effectiveness of game and simulation exercises. The four levels which Kirkpatrick described to evaluate trainings are like the following;

- **Level 1 – Reaction:** it is described as measuring the satisfaction of learners. It is an important aspect in evaluations because according to Kirkpatrick if learners have positive reactions for the training, it might yield positive results. However, if the learners' reaction to the training is negative, the possibility of the realization of learning would be definitely prevented.

- **Level 2 – Learning:** it is described as up to what point learners would realize changes in their attitudes, increase and develop their knowledge and skills due to attending the program.
- **Level 3 – Behavior:** it demonstrates in what amount learners can transfer their knowledge which they got from training to other situations and contexts.
- **Level 4 – Results:** this level indicates what benefits in outputs are achieved as a result of applied training methodology. These outputs can be defined as quality, costs, turnovers, profits, etc. in a business environment whereas they can be defined as the number and quality of job offers, salary offers, etc. from the students' perspective (Schumann, Anderson, Scott, Lawton, 2001).

Hainey (2010) conducts a study grounding on literature review and surveys and bring out an evaluation framework for Game Based Learning. His framework consists of 7 categories, one is optional, and can be summarized as the following. The first category is named as **"Learner Performance"** and the main concern of this dimension is to figure out if there has been an improvement in the performance of learners due to playing the game. For example, improvements in gaining knowledge and/or new skills may occur. The second category is **"Learner/Instructor Motivation"** in which focuses on up to what level learners' and instructors' interest will be attracted and they will be motivated by feeling themselves engaged to the particular game experience. In this dimension, the points which may affect teachers to apply a game in their teaching program. The next and third category is **"Learner/Instructor Perceptions".** This category aims to assess the understanding of the time during a game play, the reality provided thanks to the game play and complexity the game includes. It is included also in this category that how learners support themselves by means of playing the game. Perceptions of learners and instructors are crucial evaluation criteria. The fourth category is **"Learner/Instructor Attitudes"** in which it is focused on how learners' and instructors' feelings are towards the elements of the game which may have impacts on the effectiveness of the game. The next and fifth category is named as **"Learner/Instructor Preferences"**. In this category, he refers to Kolb's (1984) experiential cycle and the existence of different learning styles for each

learner and aims to assess the preferences of learners and instructors while experiencing a particular game environment. For example, if teachers will prefer to use game application for teaching a particular subject and when they plan to do it. The sixth dimension is **"Game Based Learning Environment"**. This category contains the dimensions which have the potential to be assessed about the game based learning environment. The last, and the optional category is, **"Collaboration"** which is dependent on the level at which game is played. The game can be played on an individual level, cooperative - competitive group level, or cooperating groups which have the rivalry against each other.

Tzu and Hung (2011) developed a theoretical framework which makes researchers and educators have a more complete picture regarding the effectiveness of serious game. It contains four aspects and they claimed that a game has to take into consideration all of these dimension so that it can be considered as an effective serious educational game. In the following, it can be seen in detailed how they conducted their classification. The four aspects they have considered are;

- **Game features:** Following features for any type of games need to be considered in order to have a good and effective game; rules/goals, sensory stimuli, imagination, challenge, control, interactivity
- **Immersion:** It has been stated in their argument that, players' experiences have to be taken into account for a complete evaluation and they specified immersion in three sub-titles grounding on the research which Cheng (2011) has conducted and suggested three levels of immersion; engagement, engrossment, total immersion
- **Pedagogy:** According to Tzu and Hung (2011), the desired educational objects might fail as long as they do not have entrenched teaching and learning models and they demonstrated the pedagogical perspective in five sections; context, representation, prior experience, reflection, transfer
- **Knowledge:** Unless the knowledge and skills of players in a specific content increase, it will not be a complete educational game.

Finally, de Freitas and Oliver (2006) presented a framework for evaluation the effectiveness of serious games with focusing on tutors' interest. They explain that a few efforts have been done to assist teachers in order to assess the learning impact of the

simulation and serious games. At present, when teachers are considering to employ a game for a specific learning purpose, some questions arise. Which games they need to choose to support a particular learning context? Or, what is the effectiveness of selected games? They highlight four main factors in order to design and evaluate simulation and serious games so that the questions of teachers who are looking for an efficient learning method can be responded.

As shown in figure 6, **"Context"** represents where the learning and game happens, the structure of its application and how it is supported by technical tools. These factors support learners to overcome different challenges during the game. **"Learners"** is the second one that describes factors related to learners that can impact on learning effectiveness such as learners' preferences, level, age and background. As the third attributes, **"Mode of representation"** represents interactivity, the level of immersion and the level of fidelity considered in the game or simulation. Specifically, the role of briefing and debriefing in order to boost the learning outcomes that happens before and after an educational game is considered in this part. Finally, **"Pedagogy"** is designed to stimulate the participants about the method, model and theories applied to enhance learning outcomes. E-Contents, advances software and e-Assessment are some examples in this final aspect.

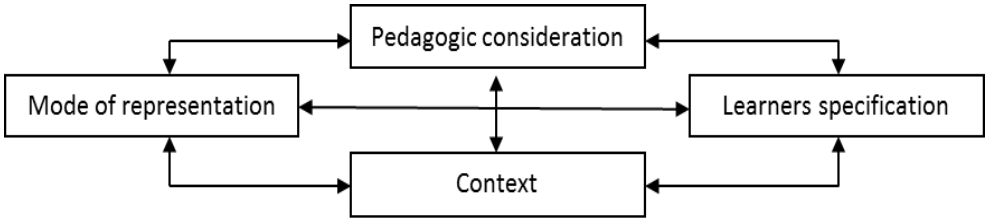

Figure 6: Four Dimensional Framework (Freitas and Oliver, 2006)

3.3.1.2 Developing a Theoretical Framework for Assessing the Effectiveness of Serious Games

In our research, it is quite important to use a relevant evaluation framework to assess the effectiveness of serious games from the teachers' perspective. Although all frameworks which are explained in the previous section have both similar and different perspectives regarding the evaluation of serious games, there is a lack of specifc efforts in evaluating serious games in manufacturing education.

In this research, it is aimed to develop a theoretical evaluation framework to answer our second research question by adapting some dimensions directly or by grouping similar ones that we have come up among the existing evaluation frameworks in the literature

so that we can have a reliable evaluation study regarding the effectiveness of serious games from the teachers' point of view. To consider a serious game as an effective one, we claim on 5 dimensions that can be included in the evaluation framework. The dimensions developed are; "Essential Game Attributes", "Knowledge & Skills Acquisition of Learners", "Learners' and Tutors' Responses", "Creation of Commitment" and "Modes of Implementation". The concept of the evaluation framework is visualized in figure 7.

Figure 7: Effective Serious Games Evaluation Dimensions

This framework can be used as a support tool in redesigning phase of any serious game because of its ability to point out the missing points of a game based learning application and can also be used as a useful measurement tool by instructors regarding the effectiveness of serious games to be used in their teaching program. Dimensions created in this framework can be explained more in detail as the following;

Essential Game Attributes

All video games have their own unique features. For instance, Appelman and Wilson (2006) states that there are six characteristics of games, and these are challenge, rules, interaction, contrivance, obstacles and closure. Malone and Lepper (1997) claims that four important features of the games which motivate players individually are challenge, fantasy, curiosity and control. As it is stated in Tzu and Hung's (2011) theoretical framework, Garris et al., (2002) discussed that although there are many different studies

discussing different terms, all researches come up with similar game attributes. In accordance with the literature, in our research, we use Rules/Goals, Sensory Stimuli, Imagination, Control, Challenge, and Interactivity as essential game attributes like Tzu and Hung (2011) employed in their evaluation framework of Serious Educational Games and we argue that an effective serious game must have these attributes. These attributes can be explained in more detail as the following;

- **Rules and Goals:** The rules of a game indicates how the goal structure of a game is Garris et al., (2002) and according to the most robust findings in the literature clear, specific and difficult objectives facilitate an enhancement in the performance. Van Staalduinen (2010) describes rules as elements composing the inner, formal structure of the games which puts limits on the actions of the players for creating winning criterions. He also explains that goals and objectives describe the winning conditions of the game which can be stable or subject to change depending on specific situations, and player actions. Having clear rules and goals in a game facilitates its players to achieve specific outcomes because players can know about what they are expected to do during game play what they are expected to accomplish. Having specific rules in a game also results in challenge creation.
- **Sensory Stimuli:** Games result in accepting another type of realism for a short time (Garris et al., 2002). Games which can awaken the attention of players by means of sound effects, graphics, colors and etc. are considered as having a potential to stimulate its players.
- **Imagination:** It is the level of a virtual world (a second life) excluded from real life in which players are isolated from real time effects so that they will not have any apprehension during their game play experience which might increase the effectiveness of end results.
- **Control:** Control stands for the ability of regulating, directing or commanding (Garris et al., 2002). The virtual environment which is created in the game should be responding to the actions of the players so that there will be some decisions to take for the players. Van Staalduinen (2010) states that in order to apply control, the learner should be able to active in decision making in the story. Learner will feel the options are unrestricted when there is a rich control.

- **Challenge:** It can be described as the difficulty level that the game has. Malone and Lepper (1988) suggest that there should be uncertain outcomes in a game by means of having different difficulty levels, establishing variable level of goals, hiding information in order to make players search for missing elements and by involving randomness. In these circumstances, degree of challenge is affected by the skills of players, time given for playing and clearly defined goals. Van Staalduinen (2010) explains challenge as the level of difficulty and probability of achieving goals that the player has during the game play and it adds fun and competition elements into the game by means of creating barriers between the current condition and goal condition. He also states that once it is combined with feedback, an organized difficulty level is provided as the learner continues his progress.
- **Interactivity:** There exist two types of interactivity in games. One is human to computer, and the other one is human to human interactivity. Human to computer activity is provided by instant feedback during game play so that players will know how they are doing in the game and change their decisions according to that. Human to human interactivity is based on social relation skills, players can improve their social skills if the game allows them to communicate with other players.

Knowledge & Skills Acquisition of Learners

One of the major goals in a serious game can be considered as facilitating learning and new skills acquisition for players. In this dimension, it is aimed to assess how interacting with this new virtual environments affect attitude changes resulting in increasing the knowledge and thus the skills of the players. Another important indicator of this dimension can be described as up to what extent a game can make knowledge and skills acquisition possible for students who are coming from different backgrounds with different disciplines, so to say that will the game be able to make students with different prior knowledge about the relevant topic to reach the same level of knowledge as a result of playing it? Finally, to be able to use/transfer these newly acquired skills in different concepts/situations is an important parameter whilst assessing the effectiveness of serious games. When a serious game is facilitating knowledge and skills acquisition

of learners and also enables them to use this new knowledge in other situations can be considered as a well-built serious game.

Learners' and Tutors' Responses

The responses which learners and as well as tutors give towards this new way of learning/teaching method have a crucial role in assessing the effectiveness of a serious game. If we consider Kirkpatrick's (1994) four levels for evaluating the effectiveness of training programs, it is very important how people who are participating in the program are going to respond to it. As a result of a negative reflection of students in a classroom context, it can be said that the possibility of facilitation of learning will be reduced to zero whereas a positive respond does not completely guarantee the occurrence of learning. Hainey (2010) claims that not only learners' but also the motivation of the tutors become also important in these cases. Will the participants be willing to play the game more than one time? What do the tutors think about the serious game as a new learning/teaching tool and does it have the potential to be used in classroom context to facilitate learning? For these reasons, identifying specified issues might become crucial so as to decide if tutors consider the serious game as an effective method for learning.

Creation of Commitment

Game attributes are useful in motivation of players but having specific game features does not mean that players enjoy playing it (Tzu and Hung, 2011). Therefore there is a new concept that needs to be examined. The name of this concept is flow which is first introduced by Csikszentmihalyi (1990). It can be described as committing all the attention of learners to the task up to a level that distracting the learner will become really difficult and the learner will lose track of time passing because he/she is so immersed in learning process that he/she will not be aware of the external environment but only the learning environment. Jones (1998) summarizes eight criteria which lead to the achievement of flow; capability of task to be completed, capability of learners to concentrate on task, having clear goals, providing prompt feedback, learners' control over their actions, transformation of time, self-unconsciousness and deep but effortless involvement in task. Educational games should not be expected to satisfy these criterions as much as entertainment games do but it is important also for educational games to make learners experience the flow during their experience in order to have effective learning achievements.

Modes of Implementation

When applying a new educational concept such as serious games, the ways that tutors will implement them in the classroom context becomes vital in order to achieve desired results. For example, it becomes an important issue if the learners should play the game in groups or as individuals in the classroom or at their home to be able to achieve preferred results thanks to playing the serious game. In this dimension, the terms briefing and debriefing becomes quite critical as well. Since a new learning method is aimed to introduced by tutors to their students, students have to be supported efficiently so as not to be frustrated and have prejudices towards the game and consequently not to have a negative approach which might prevent them from learning. Also during the game design phase, it must be considered that the target group who is going to experience this new method of learning has to be provided sufficient support. Hays (2005) states that, "If instructional games are containing debriefing and feedback, they are more effective". Dorn (1989) recommends that debriefing should be included after the game and bring meaning to the experience. And again according to Hays (2005), games are considered to be more effective if they are followed by a debriefing session to emphasize the significance of game experiences. Therefore we can say that, briefing and debriefing terms are crucial elements in a serious game application and the necessary attention has to be given to them both by tutors during they experience the game with their students, and also by game designers during the development phase of serious games so as to include necessary support features for the learners and as a result facilitating learning for them.

4. IMPLEMENTATION OF A STUDY TO EVALUATE A SERIOUS GAME IN SUSTAINABLE MANUFACTURING

4.1 Presenting SGM Serious Game Structure

4.1.1 Overview

Duin et al., (2012) states that CEOs frequently assign the improvement, implementation and management of a sustainability strategy to a sustainable manager whose position is horizontally aligned. The sustainable manager aims to introduce sustainability in manufacturing regularly outcomes unpredictable and surplus side effects. For instance making a product greener the manufacturing processes may produce more pollution. Also predominant reasoning in a manufacturing venture is cost driven that indicates the sustainability manager has a complicated and challenging mission of engaging with the all team in the direction of accomplishing greater sustainability, assuming a more holistic method to decision making and reasoning. This involves a greater difficulty in reasoning and decisions making of the individual that increases hard challenges for training and competence improvement tools. A talented method getting greater recognition and establishing enhanced return on learning, is the utilization of Serious Games (Filho and Latham 2006).

4.1.2 Introduction

TARGET is called as a technology enhanced learning platform that is developed throughout the serious gaming approach (Fradinho, Andersen, Lefrere, and Oliveira, 2009). It seeks quick competence improvement particularly in the field of soft skills and complex competences. A novel game scenario designed for the TARGET platform was improved with the purpose of to assist the achievement of competences in the area of Sustainable Global Manufacturing. Sustainable Global Manufacturing (SGM) serious game is built on the Life Cycle Assessment (LCA) approach that allows the evaluation of environmental impacts of manufacturing products, managing manufacturing processes and managing production sites.

University students who are key target audiences of this game are trained in Sustainable Global Manufacturing concept by improving their “communication and negotiation skills”; “system thinking”; “ability to see the big picture”; short vs. “long term strategies” and “critical thinking”.

4.1.3 Story Scope

The game scenario considers the stages a venture has to run while dealing with sustainability issues. In the game scenario the player is assigned as a Sustainability Manager of an internationally operating manufacturing company. This company produces household machinery such as coffee machines. The player who finds him/herself in a numerous of critical events is faced up to the strategy described by the CEO in order to make the products and the processes of a manufacturing corporation sustainable and convincing the other managerial employees in order to accept and execute the planned strategy. His/her duty is describing objectives, goals and boundaries of the LCA in order to obtain knowledge about the manufacturing by identifying an energy and materials flowchart, gathering pertinent data and clarifying the outcomes. In order to achieve this task the player has to be aware of the difficulties of the LCA process in addition to preserve successful social relationships with managers. Involving characters in the game are CEO, Production Manager, Shift Manager and Sustainability Manager. Except Sustainability Manager all characters in the game are non player characters. They are driven by the game engine. The information regarding to characters is given below.

Characters in the game

- Sustainability Manager (Mark – Playable Character)
- CEO (Davida – Non Playable Character) She aspires that company has to earn more money. She desires to go green for the reason that it's a chance to company and a liability concerning future generations.
- Production Manager (Christopher – Non Playable Character) He doesn't support the sustainability program because from his point of view it is ineffective. He is selfish and goes for himself.
- Shift Manager (Klaus – Non Playable Character) He works well in the company to earn his salary.

Background information of the production

The whole life cycle of the coffee machine XC 100 G is composed of manufacturing and usage. The Bill of Materials (BOM) are listed as: Housing; Mains Cable, Coffee Pot and Smart Parts.

The required manufacturing processes and the materials for manufacturing are presented in figure 8.

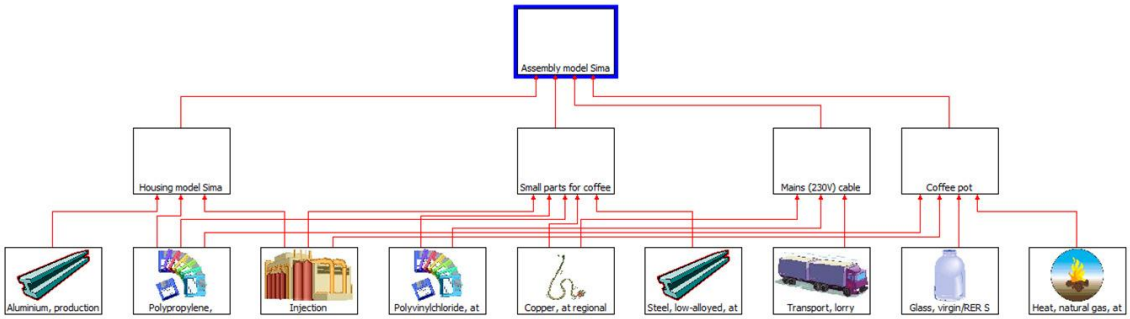

Figure 8:Breakdown of the Production Process of the Coffee Machine XC 100 G (Retrieved from TARGET Deliverable 11.4, Duin et al., 2012)

The housing, mains cable, some small parts and the coffee pot are collected in assembly process. The materials and services which are used in manufacturing are listed as: Aluminium, Polypropylene, Injection, Copper, Steel, Transport, Glass, and Heat (provided through natural gas)

The game scenario is based on Life Cycle Assessment that is an approach to assess environmental impacts throughout whole stages of a product's life cycle. The key phases of Life cycle assessment are shown in green colored boxes in figure below (Fig. 9). The task of the of the player starts with "setting objectives and goals" and it is followed by defining boundaries, selecting flow chart, defining input and outputs, data collection, choosing impact categories and finally interpretation of results. The red colored boxes indicate required action after each of these phases. These actions are mostly performed in LCA virtual tool that is explained later.

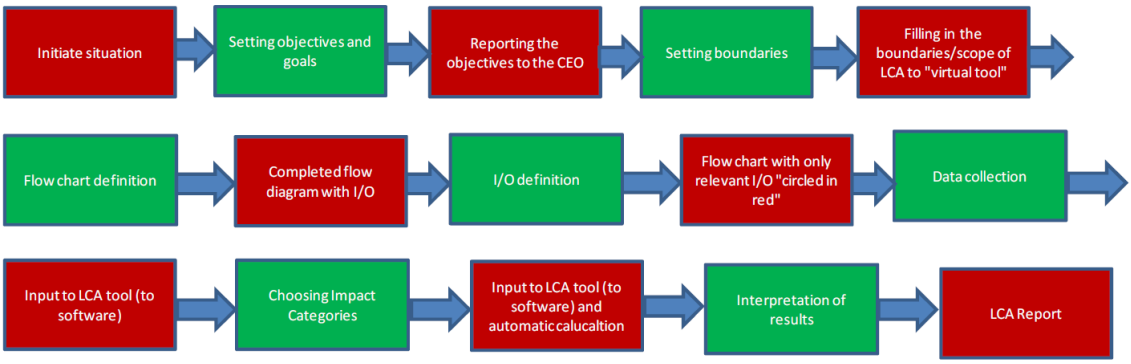

Figure 9: Process of performing a LCA (Retrieved from TARGET Deliverable 11.4, Duin et al., 2012)

4.1.4 Overview on the Game Scenario

In this game scenario it is aimed to improve two main competences. The first stage is ability to conduct a LCA and second one is ability to use a LCA as it is seen in figure below (Fig. 10). The second stage requires the competence of systematic thinking.

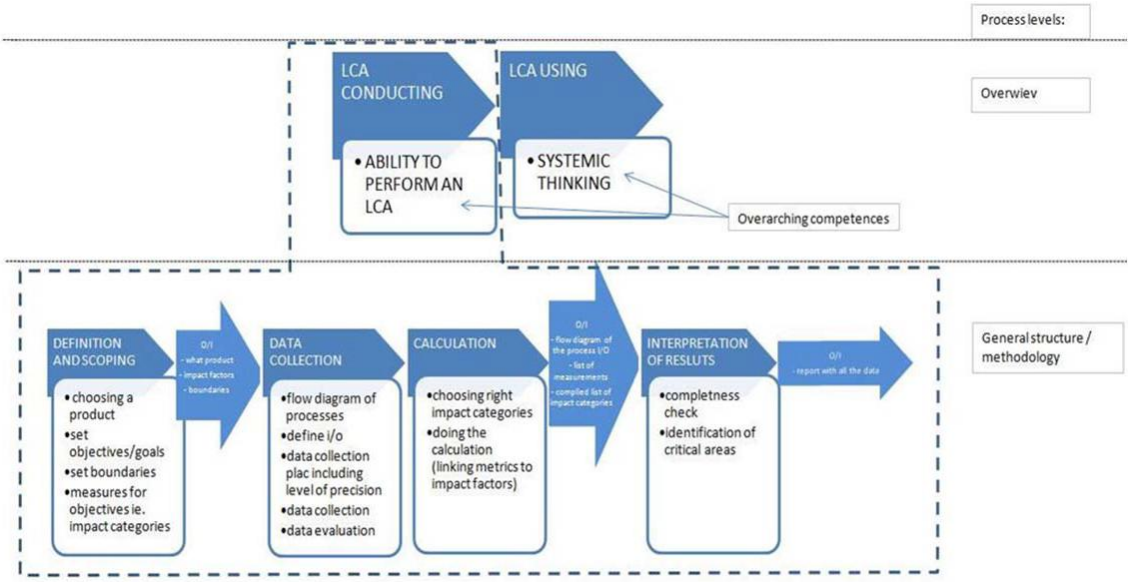

Figure 10: Overview on the Sustainable Global Manufacturing Game Scenario (Retrieved from Duin et al., 2011)

The first stage (LCA Conducting) is usually composed of four levels. Initially it starts with the definition and scoping of the LCA. The outcome of the LCA is directly affected by choosing of objectives and goals. An incorrect choice will cause unenthusiastic impacts on the whole quality, time and costs of the LCA plan. The challenge here is to gather accurate information from any sources. It is up to player to choose the right person who can provide that information. The player is generally engaged in verbal communication with either the CEO, production manager or a shift manager by using dialogue boxes that appear during the conversations contain the different topics of talking. As it is seen in figure 11, the top level "situated context Talking to Someone" is able to be split into three situations such as "Talking to CEO", "Talking to a Manager" (production manager) and "Talking to a Shift Manager". The diverse issues interest in talking about relevant phase of the LCA process such as "Setting Objectives and Goals", Define the Boundaries", Define the Flowchart" and "Data Gathering."

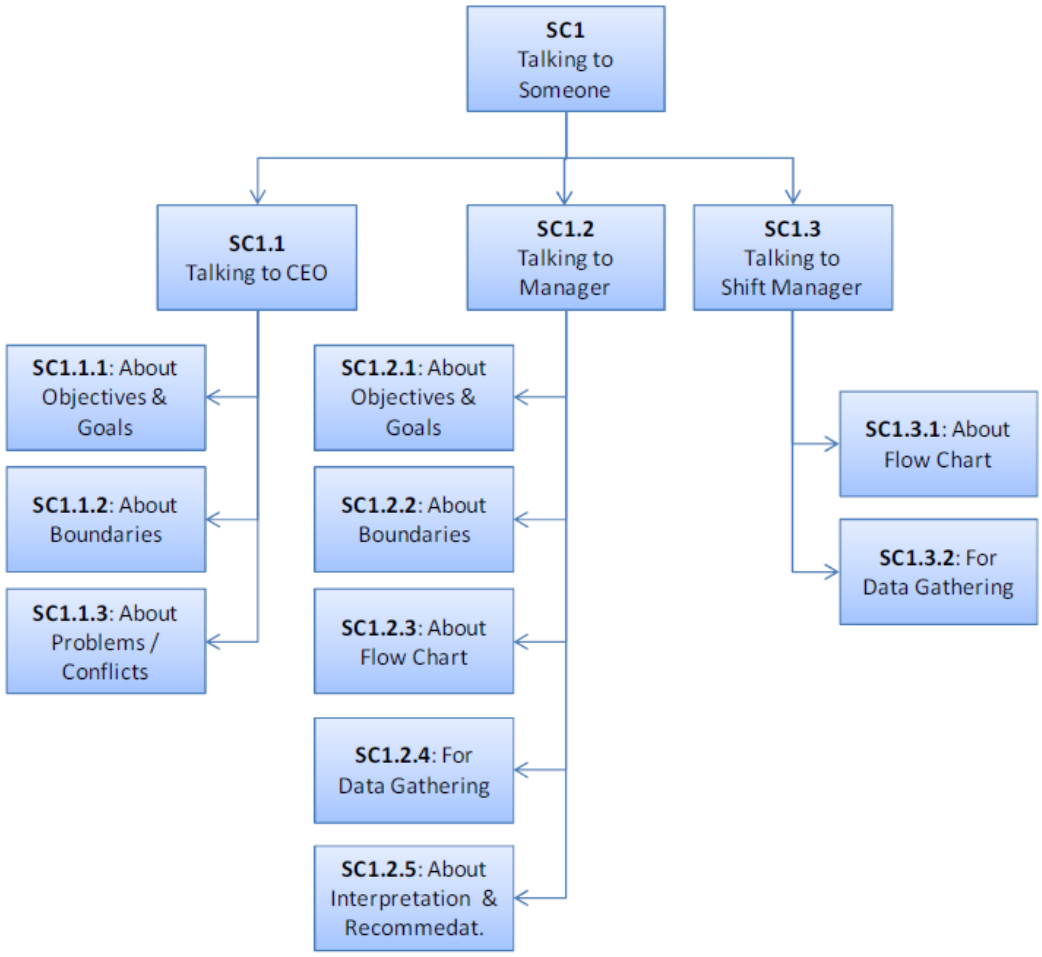

Figure 11: Hierarchical Breakdown of Situated Context "Talking to Someone" (Retrieved from TARGET Deliverable 11.4)

In addition, a winning game story dialogue can be found in Appendix B. Except verbal communication it is possible to access Enterprise Resource Planning program by using available computers and smart tables.

In the game all of the characters concern discussing about the phases of the LCA processes. The player has to describe the scope of LCA to outline the use of time and resources efficiently, getting the final outcomes and definition of boundaries in a better way. The decision of choosing any departments and processes that are included in the LCA is related to the system boundary.

The second stage is related to data collection. The player will be more familiar to gather a relevant data by means of the determination of inputs and outputs in every process. The player has to identify measurement units accurately. Any wrong data will guide to incorrect outcomes and consequently quality, time and cost indicators of project are affected unenthusiastically. The determination and choice of the correct impact

categories for performing the LCA may affect the general time, quality and cost of LCA project.

The third stage is for computation. Nevertheless the whole LCA process is built on data and the capability of the player in order to secure accomplished and precise data. There are several options in order to perform LCA process in real life. In this game discovering the most successful order is a challenge for the player.

The LCA Using stage is not described in detailed because of the fact that game developers are still improving it.

After gathering all required information and data during the game play the player open LCA virtual tool in order to select boundary, flowchart, inputs/outputs and enter input/output values and choose impact categories. When it is completed they player is ready to compute LCA.

4.1.5 LCA Virtual Tool

As it is stated above the first phase of the LCA assessment is selecting boundary. When the player access to LCA virtual tool he/she should choose the boundary that is chosen among “Whole Lifecycle”, “Production” and “Supply Chain”.

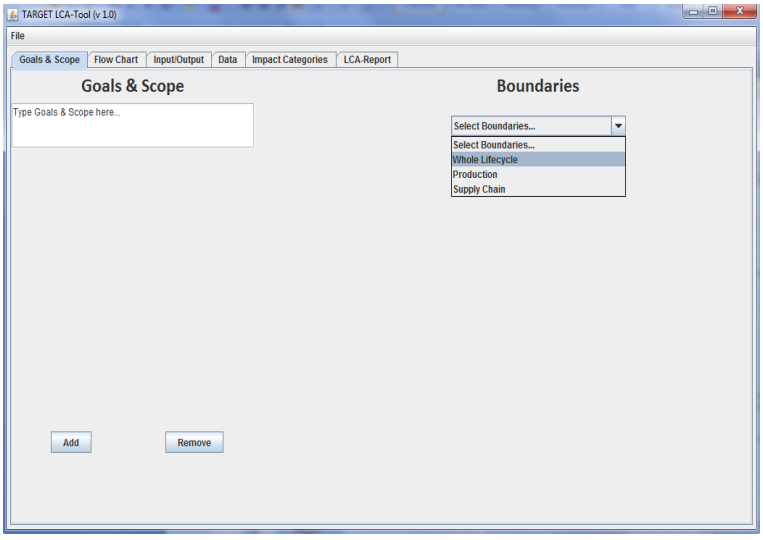

Figure 12: Boundary selection in LCA virtual tool of SGM serious game

Selecting the Completed flow chart

The second phase is flowchart selection. Flow charts vary from each other regarding to chosen boundary. The player needs to choose the flowchart that suits best to the production process.

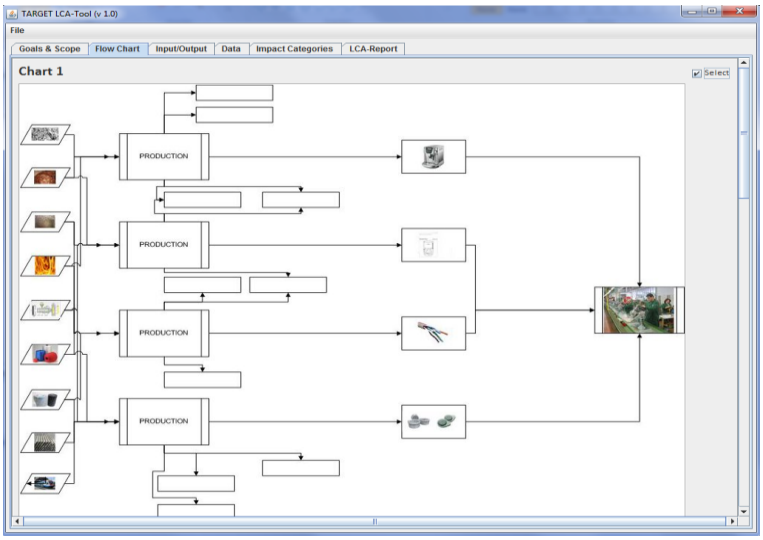

Figure 13: Flow chart selection in LCA virtual tool of SGM serious game

Inputs/outputs selection

The next phase is choosing relevant inputs and outputs gathered from both Production Manager and Shift Manager.

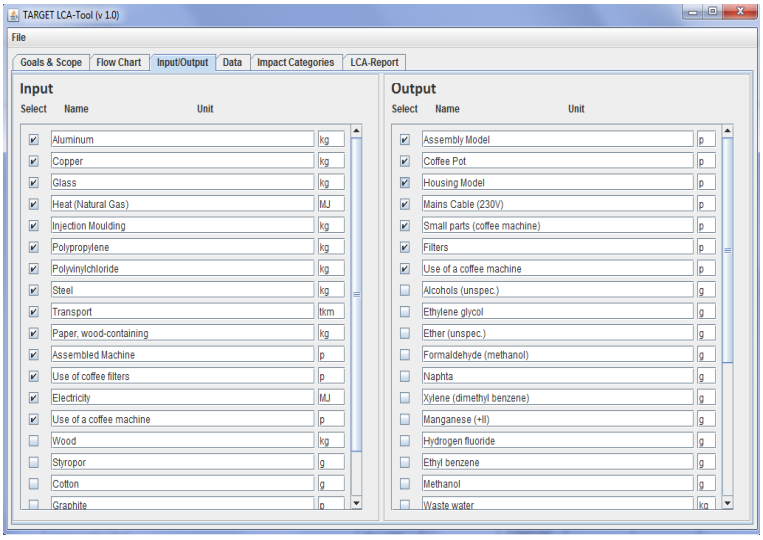

Figure 14: Input/output selection in LCA virtual tool of SGM serious game

Putting values of Inputs/outputs

The values of inputs/outputs that are collected from both Production Manager and Shift Manager are entered in this table.

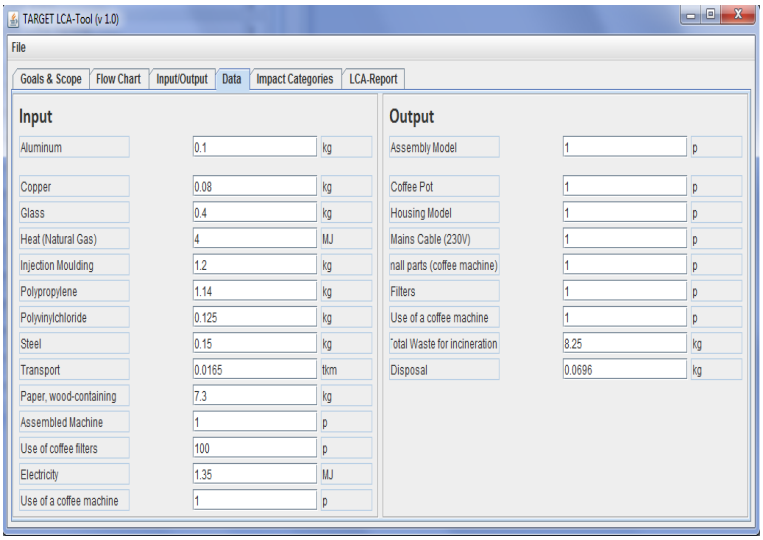

Figure 15: Input/output data entering in LCA virtual tool of SGM serious game

Choosing Impact Categories

The impact categories are provided from both CEO and Production Manager. First of all it is required to select whole impact categories. Then the player clicks on the Compute LCA button.

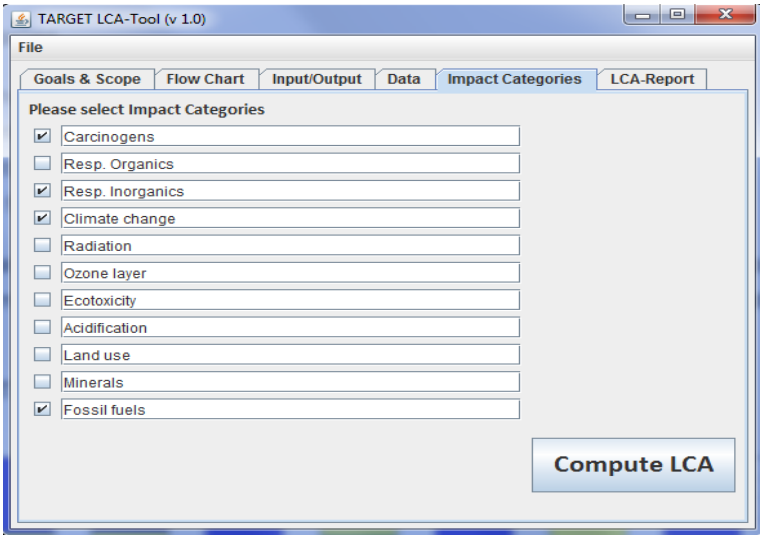

Figure 16: Impact categories selection Report in LCA virtual tool of SGM serious game

LCA Report

At the end of the game, the player can have access to Competence Performance Analyzer where he can watch his recorded game play and read the dialogues he performed and also he can see from the graph how different performance indicators of his were changed in relation with the time

This report represents the effects of the whole impact categories before conducting a LCA.

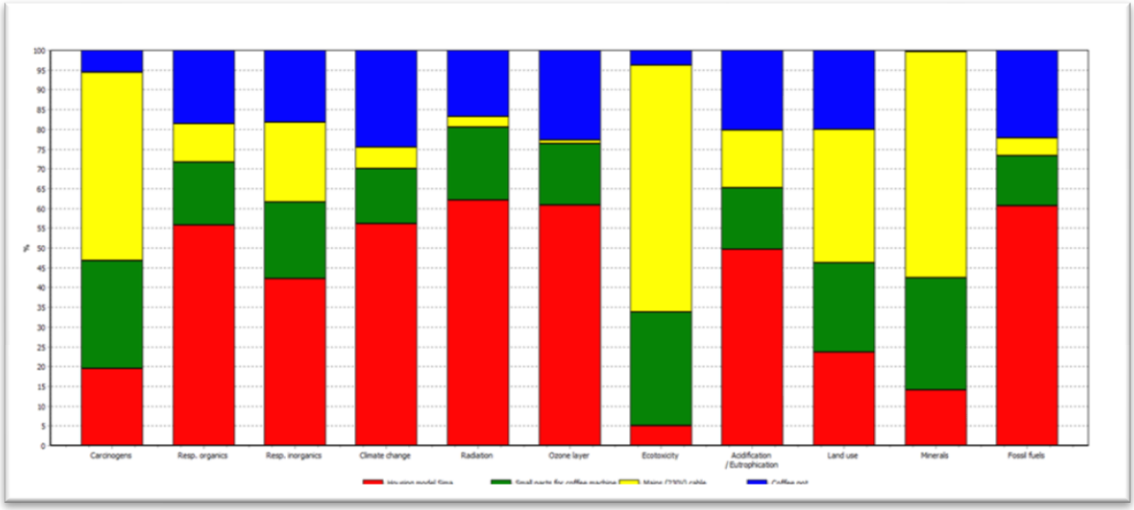

Figure 17: LCA Report without Normalization in LCA virtual tool of SGM serious game

LCA Report (Normalized)

This normalized graph of LCA Report which indicates the impact categories of the process which are calculated based on the decisions taken by the player (i.e. which boundary and flowchart to be selected) and information gathered (i.e.input/output values) during the game play experience. The impact categories that have the highest effect to environment are specified. Throughout this report the player observes which ones should be selected.

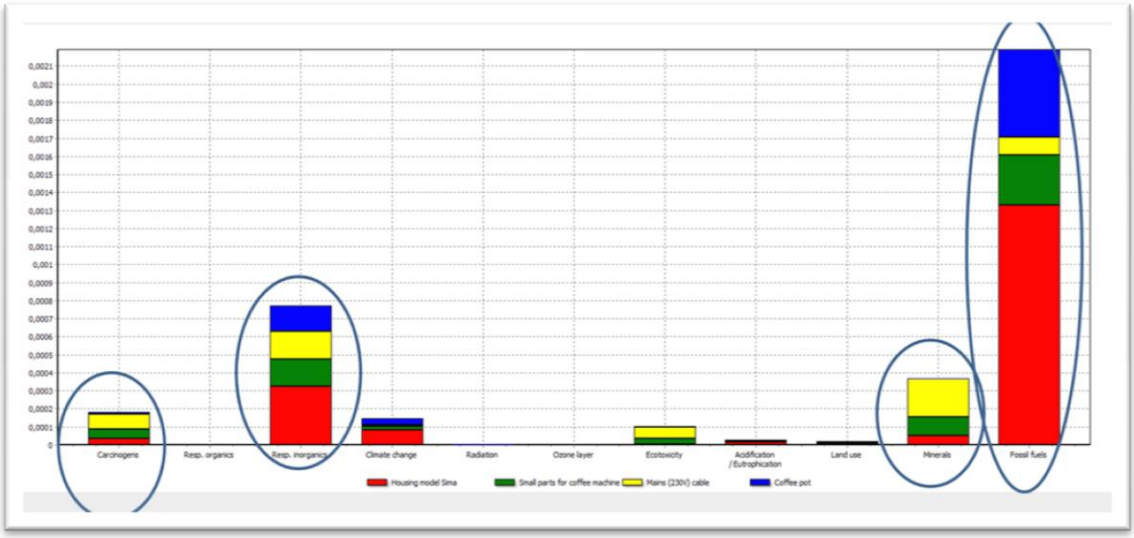

Figure 18: LCA Report with Normalization in LCA virtual tool of SGM serious game

4.1.6 Competence Performance Analyzer Tool

At the end of the game, the player can have access to Competence Performance Analyzer where he can watch his recorded game play and read the dialogues he performed and also he can see from the graph how different performance indicators of his were changed in relation with the time.

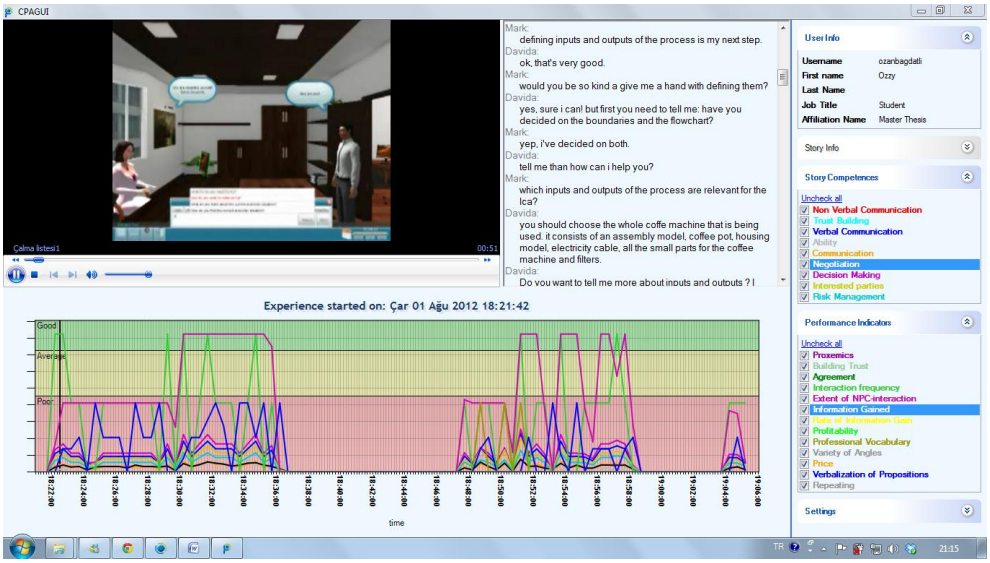

Figure 19: CPA tool of SGM serious game

4.2 Implementation of SGM Serious Game's Effectiveness Evaluation

4.2.1 Background

Our evaluation session was conducted in October 2012. Our focus group in this study was teachers who are teaching a relevant course or working in sustainable manufacturing and performing a Life Cycle Assessment. The evaluation was realized by a video presentation which was made based on reflecting the features of TARGET client version 0.41.4 and tested the SGM scenario.

Our evaluation of SGM Serious game aims to assess the effectiveness of this serious game from the teachers' point of view. In this research we conducted an evaluation with teachers of DIG (Dipartimento di Ingegneria Gestionale) in Politecnico di Milano who have taught relevant courses to sustainable global manufacturing in order to assess if this serious game is effective to achieve its objective when it is used in teaching Sustainability/Life Cycle Assessment subjects in a university course. Therefore this research provides to have an insight about the teachers' approaches towards deploying

SGM serious game in their teaching curricula. While the effectiveness of SGM serious game is evaluated, this study also provides valuable comments to contribute to the game development.

In order to answer the research question, we reviewed existing serious games evaluation frameworks by focusing on teachers' perspective to create a reliable one considering the area of our research, teaching Sustainable Global Manufacturing issues and performing a Life Cycle Assessment. After analyzing four prominent models, a theoretical framework which underlay this evaluation study was built as it was discussed in more details in the previous sections.

Since the game was still in its development process when this evaluation study was held, it is decided to create a game presentation video which reflects all features of SGM serious game and present it to the teachers who take part in this study to be able increase the reliability of the evaluation session.

Our sessions were composed of 3 stages. First it started with a briefing of the game, and secondly continued simultaneously with video presentation and debriefing, and finally with a semi structured interview took place individually with all the participants.

4.2.2 Preparation of Game Presentation Video

As it is stated before SGM serious game was not developed completely yet when the evaluation study was conducted. In order not to make this situation affect evaluation process of teachers and to avoid bias, a game presentation video was decided to be created.

For this reason, it was aimed to create a full game play experience presentation video by using "Camtasia Studio 8" software by aggregating the missing points of the SGM serious game by combining different materials that we had and thus resulting in an expected full game experience as TARGET platform's 0.41.4 version will offer to its users once it is completely developed. As a result, a game presentation video with a length of 18 minutes and 45 seconds was created which was supported with background music, subtitles and additional features offered by Camtasia Studio 8 software in order to make our participants who watch the presentation and take part in our evaluation sessions informed well about SGM Serious Game.

The game presentation video is planned to be produced containing three different parts. The first part (1 minute 37 seconds) was planned to introduce how the game will be

launched and begin running and how a game play can start. In this part, the participants have been informed about how they can get information about the characters of the game and how they can control the characters using the keyboard. The second part of the game presentation video (around 14 minutes and 10 seconds) was planned to introduce a winning story in which a player can accomplish all the steps in SGM Serious Game from the beginning to the end to perform a life cycle analysis. In this part of the video, participants were able to watch how the Dialogue, Life Cycle Assessment and Competence Performance Analyzer tools work, how the player can reach to ERP/MRP system of the company, and how the player can use game features such as teleporting to another department. Thus the second part of the presentation started with a dialogue between Mark (Playable Character – Sustainability Manager) and Davida for the boundaries of the LCA (Non playable Character – CEO) and then continued with the dialogue of Mark with Christopher (Non playable Character – Production Manager) for the flowchart selection and input/output values and finally with the dialogue of Mark with Klaus (Non playable Character – Shift Manager) for the most accurate input/output values of the process. After the data gathering section from the dialogues and the ERP/MRP System, LCA tool was started and the information gathered about boundaries, flowcharts, and input/output values were inserted in the system so that the player could get a Life Cycle Assessment report. The last and the third part (around 3 minutes) demonstrated how would the answers gathered from dialogues and results obtained after computing LCA would change since a player would progress in a different way while playing the game and thus would get unreliable and different LCA report results from the winning scenario which was described in the 2nd part of the video presentation.

The SGM serious game presentation video was produced by aggregating different materials that we had as it was stated before. To be more specific, we had had several recordings of game play experiences that we could perform at different times when it was possible to reach the game server. And additionally, we had the chance to reach some data that some of the developers provided us. By using all data and resources that we had in our hands, we came up with the SGM game video presentation which had meaningful dialogues with all the characters, an enhanced LCA Tool with more flowcharts and a computation of LCA whereas the game itself has a very simple one which does not work properly, visualization of Competence Performance Analyzer

(CPA) tool which was disabled in the SGM demo version but it is an important feature which helps to measure and indicate the performances of players.

Creating a complete game experience, to dismiss these missing points and to fully reflect the potential game improvements, was a crucial milestone in our research so that it would be possible for us to realize an evaluation session with teachers to assess the effectiveness of SGM serious game from the point of view of them in case it will can used in a classroom context to teach sustainability and life cycle assessment.

A story board for the video game presentation is shown in the following section;

4.2.3 Story Board of Video Game Presentation

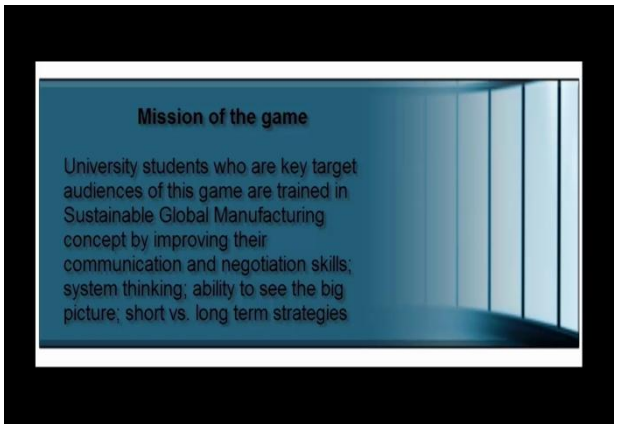

Figure 20: Explanation of the objectives

The video game presentation video starts with explaining the objectives of SGM Serious Game.

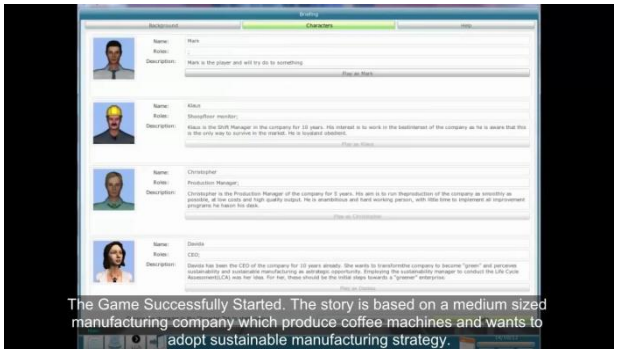

Figure 21: Information about the characters

The game successfully started. Information about the characters and the virtual company's background can be reached from the menu.

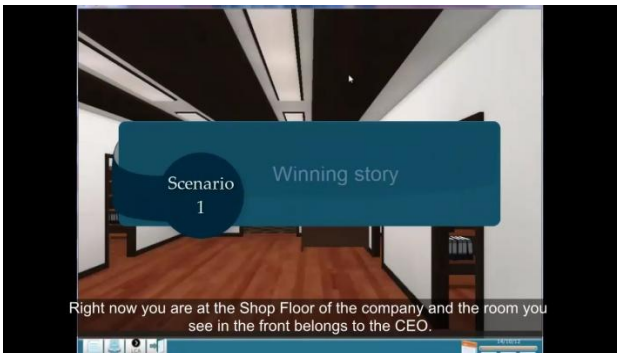

Figure 22: Starting to game

A sample winning game story's game play recording starts next.

Figure 23: Conversations with CEO

The only playable character in the game, Mark (Sustainability Manager), starts first talking to CEO about the boundaries of the LCA until he gathers information about them from her.

Figure 24: Conversation with Production Manager

Then Mark continues his conversations with the production manager to gather information about the flowcharts of the processes, and the input output values.

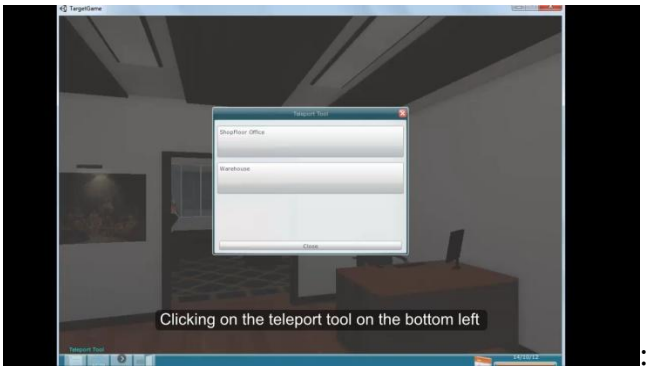

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Figure 25: Teleport tool to switch another floor

After talking to production manager, Mark can check the ERP system of the company and then teleport to warehouse so that he can talk to shift manager as well.

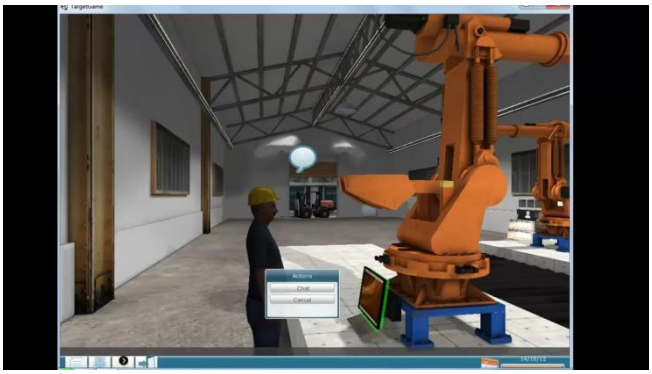

Figure 26: Conversation with Shift Manager

Talking to shift manager will result in gathering more accurate info about the values of inputs/outputs which are important for computing LCA.

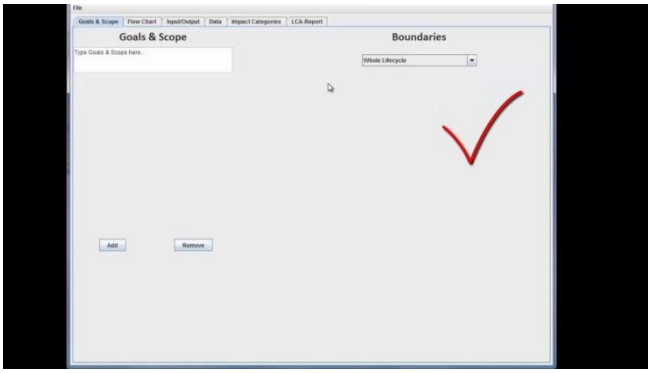

Figure 27: Selection of boundary

Once the player finishes gathering information, he starts performing LCA by clicking on the LCA Tool button and there chooses the boundary he gathered from CEO and the flowchart that is decided based on the answers from production manager.

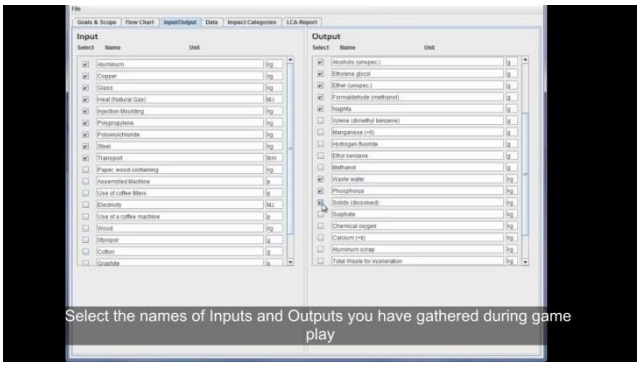

Figure 28: Input/output selection

After boundary and flowchart selection, the player fills in the input/output values according to the info that has been gathered during the game play.

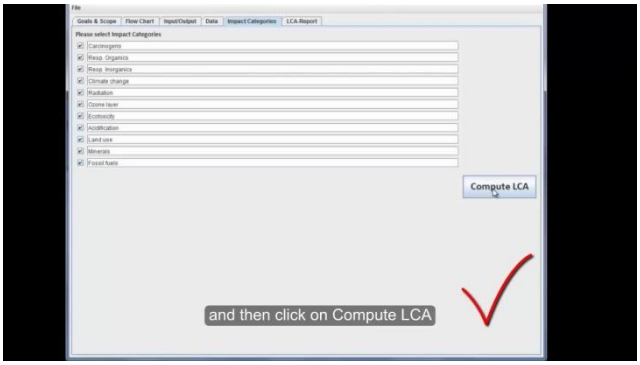

Figure 29: Selection of Impact categories

Then, the impact categories have to be selected.

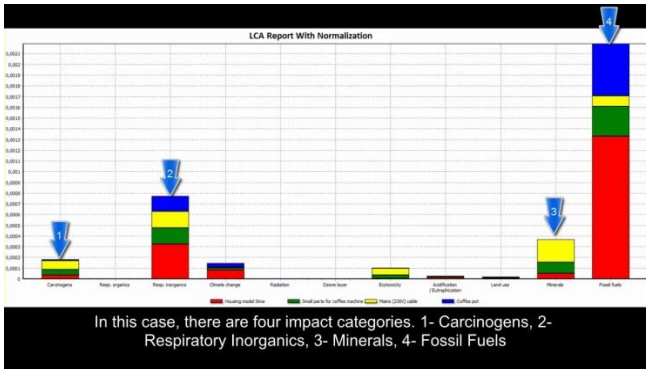

Figure 30: LCA Report with Normalization

When the selection of boundary and flowcharts, and entering the values of inputs/outputs are done, the player can click on the Compute LCA button and reaches the normalized graph of LCA Report which indicates the impact categories of the process which are based on the decisions taken by the player (i.e.

which boundary and flowchart to be selected) and information gathered (i.e.input/output values) during the game play experience.

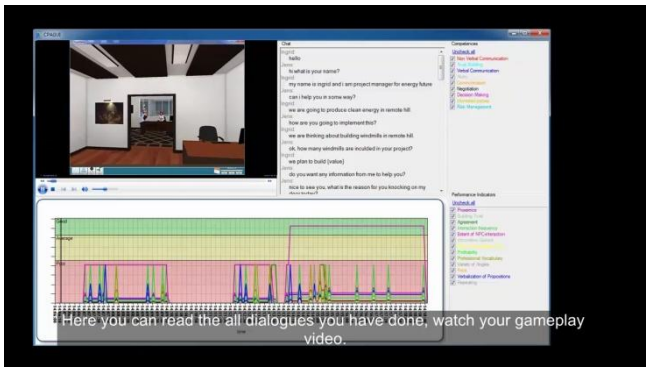

Figure 31: CPA Tool

At the end of the game, the player can have access to Competence Performance Analyzer where he can watch his recorded game play and read the dialogues he performed and also he can see from the graph how different performance indicators of his were changed in relation with the time.

4.3 Data Gathering

Regarding the literature review both in research methodologies and existing serious game evaluation frameworks, a qualitative research questionnaire (see Appendix) which consisted of 23 questions in total was created to be used in a semi structured interview format with our participants and the questions asked were prepared based on the dimensions of the reorganized evaluation framework which have been developed in Section 3.3.2.3 Before each of the individual interview sessions, our participants were asked for their consent for enabling voice recording so that the records would be used as a supportive tool while analyzing the result. 8 out of 9 participants have agreed on voice recording whereas 1 participant did not feel comfortable with that. Therefore during 1 evaluation session data collection was performed by listening to the interviewee and taking notes. Other 8 sessions' data collection was performed also with the voice recordings.

First seven questions of the evaluation questionnaire built up the "Teacher Background Questionnaire" in which background information of the participants were gathered. In the second part of the evaluation questionnaire, there were 15 questions which

constructed the core of the evaluation session. Data were collected by 1 multiple choice and deep explanation / open ended question, 5 Likert Scale (7 points) and deep explanation / open ended questions and 9 deep explanation / open ended questions. One and last question was about the participants' ideas and recommendations about the research and evaluation session. The questions, that aimed to extract the idea of teachers about the SGM serious game as well as about the points which might be important during the redesign phase of SGM Serious Game, were designed based on the reorganized theoretical serious game evaluation framework described detailed in Section 3.3.2.3 and the distribution of questions to the evaluation framework dimensions was like the following table 8;

Dimensions	Questions
Essential Game Features	Question 1 (Total of **1** question)
Knowledge & Skills Acquisition	Questions 10, 12, 11, 13, 19 (Total of **5** Questions)
Learners' and Tutors' Responses	Questions 9, 14, 15, 16, 17 (Total of **5** Questions)
Creation of Commitment	Question 22 (Total of **1** question)
Modes of Implementation	Questions 18, 20, 21 (Total of **3** questions)

Table 8: Distribution of Questions to Theoretical Evaluation Framework Dimensions

4.4 Procedure

The evaluation session was conducted in two different sessions with a total number of 9 participants on 22nd and 23rd of October at Politecnico di Milano Bovisa Campus.

1st session: 22nd of October 2012 - 4 participants

2nd session: 23rd of October 2012 - 5 participants

Each session was composed of three parts which were; firstly debriefing (around 5 minutes), secondly simultaneous video presentation monitoring and a debriefing session (around 35 minutes) and finally individual interviews with each participant (around 30 minutes)

Debriefing: In this section the main objective of the game was explained and also it was explained to the teachers who participate in this evaluation process

why they were not able to play the game itself but instead a game play presentation is being shown to them.

Video presentation: In this phase of the evaluation session, teachers watched the game presentation video whose features have been explained detailed in Section 4.2.2. While they were watching the video, they were permitted to ask for a pause whenever they had a question or needed a clarification in order to be able to better understand SGM Serious Game, and after they were satisfied with the answers game presentation video continued playing.

Individual interviews: After the demonstration of SGM serious game video presentation, all teachers were requested to perform an individual interview session during which they answered the evaluation questionnaire which was designed regarding the reorganized theoretical evaluation framework that was developed in this research and was explained in detail in Section 3.3.2.3

5. ANALYSIS OF INTERVIEW SESSIONS

The structure of this evaluation work was based on a qualitative research which was conducted by a semi-structured interview held individually with all the participants. The sample size of this study was a number of 9 teachers who taught relevant courses. The first part of the questionnaire included 7 teachers' Background Questions (BQ) and the second part included 1 Multiple Choice Question (MCQ), 5 Likert Scale Questions (LSQ) and 9 Deep Questions (DQ) which yielded the results to evaluate if the SGM Serious Game was an effective learning tool. Therefore in the following section first teachers' background and demographic data of participants will be analyzed and then the results of MCQ, LSQ and DQ will be discussed.

5.1 Teachers' Background and Demographic Data of Participants

In this study, seven questions were designed to collect data about the teachers' background who participated in evaluation sessions. Table 9 shows the demographic distribution info based on the three factors; Age, Gender and Teaching Experience. Then teachers' ideas about their experience in application of serious games in teaching are explained.

Teaching experience		Gender		Age	
< 1 Yrs	11%	Male	88%	25-29	33%
1 to 2 Yrs	33%	Female	12%	30-40	56%
2 to 3 Yrs	45%			> 40	11%
> 3 Yrs	11%				

Table 9: Participants' Demographic Distribution

In this part of the questionnaire, all of the teachers stated that they used different kind of technology in classroom while teaching. 2 of them only use Power Point in teaching whereas the others employ simulation software, online websites and videos besides using only Power Point. Amongst all, just 1 applied role playing method and one is going to put it in his teaching structure in the second semester of 2012-13.

2 out of 9 expressed that they have not played commercial computer games at all, but they believed that games have considerable potential to enhance the learning outcomes. The other 7, who have previous experience in playing game, added a significant point

that the games can increase the learning outcomes when it is properly integrated to theoretical engineering concepts. They play some kinds of computer games which mostly include strategy games (e.g. Civilization, SimCity, Sims) and also some of them are interested in playing sports (e.g. Football Manager) and role-playing games (e.g. Counter Strike). All of the participants considered computer games as useful for learning stating that games help people to understand behavior of complex systems, improve cognitive skills, and increase capability to assess different alternatives. Some of the sample answers were like the following;

"They can support my learning and help finding new concepts." (P4)

"They are good at improving decision making skills and coming with a judgement." (P8)

According to the results of the last question in the teacher background questionnaire, all 9 participants supported that generally serious games in edutainment would affect learning positively. They described serious games as a tool to cover missing points that students could not gather in university education by providing more interactive and less boring atmosphere. Just one participant stated that although serious games are practical learning methods, there is a trade of between the time spent and the results obtained from the game. This trade off has to be managed well. Some of the responses to this question were like the following;

"They make learning more interactive, less boring, students maybe can learn something by doing." (P2)

"It makes them learn better because it is not only theory. It gives them the chance to implement things they learn and to see the results." (P7)

"Serious games would help students to understand behavior of complex systems and to understand the interrelation between state variables." (P6)

"I have used serious games in the business level, but I think that they might be useful in academic level as well. The problem is that, they can be complementary tools, not independent tools. So prior knowledge is required." (P8)

5.2 Deeper Examination of the Evaluation of SGM Serious Game

In the second part of the evaluation questionnaire, participants have been asked 15 questions which were designed regarding the evaluation framework that was developed in Section 3.2.2. It was aimed to be revealed from the teachers' point of view that if the

SGM Serious Game could be useful in a classroom context while teaching sustainability and how to perform a life cycle assessment.

5.2.1 Results of MCQ

Q8. Which of the following game attributes you think the SGM serious game has? (You can choose more than one) [Essential Game Attributes Dimension]

6 attributes of the game was asked to participants in a multiple choice question format to get their opinions about if the SGM Serious Game contained those game features. It was possible to choose more than one option. The attributes which were asked were Rules/Goals, Sensory Stimuli, Imagination, Challenge, Control and Interactivity. The result is depicted in Chart 1.

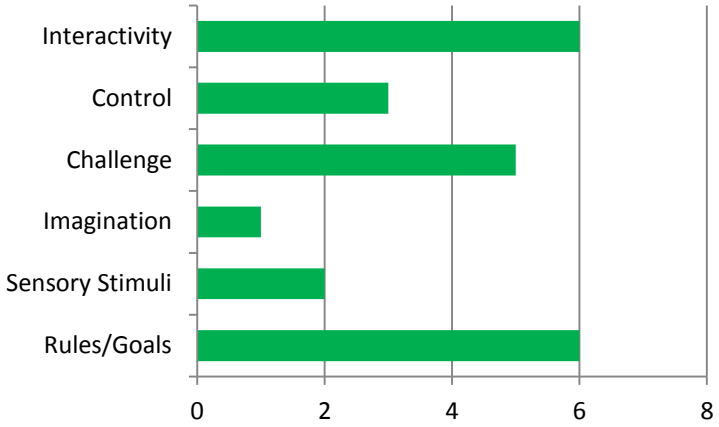

Chart 1: Results of MCQ / Game Attributes

As it can be seen from the graph that; imagination, sensory stimuli and control attributes were voted the worst compared to the other three features. imagination got 2 votes out of 9, sensory stimuli got 2 votes out of 9, and control got 3 votes out of 9. Participants stated that there was not a specific objective to be controlled, so objectives must be explained in a better way. For instance sometimes players can gather wrong information from non-playable characters and there is not a mechanism to be informed to put players in a correct direction. For imagination feature, some participants commented that the game environment does not reflect real world experience efficiently (i.e. manufacturing environments are more complex than the game environment and the dialogues in real life would be completely different than the ones game has). Challenge, interactivity and rules/goals features were voted better than the other three attributes. Challenge got 5

votes out of 9, whereas interactivity and rules/goals got 6 votes. Detailed explanations given by some participants are like the following;

"Pre-determined questions and answers avoid the game to be challenging" (P 8)

"If you do not have an objective, there will not be control. Maybe you don't get the right information and you need to be informed." (P1)

"The level of sensory stimuli is lower than other features." (P3)

"How you get the data is the challenge, and the interactivity is provided by communication." (P2)

"According to the video presentation, I have seen Rules&Goals when I saw the order of things that you have to do, for instance start with talking to CEO, then go to production manager, and so on. Challenge exists when you try to find the right person who can explain things better. And finally charts used in the game can be considered as control." (P4)

"There do not seem to be much challenge because everything is predefined already. I do not think also that this game has clear rules and goals feature because there are not many options unlike in good serious games." (P7)

"It is not challenging, there is not stress, no ups and downs. Yes, there are graphics, we can say that it s interactive but it will not create an immersion." (P5)

5.2.2 Results of LSQ

In the LSQ measure, were asked to rate 5 different questions on a scale of 1 to 7, where 1=Strongly Disagree and 7=Strongly Agree. Table 4 presents the results of the answers where ratings 1-2 are grouped as "disagree", 3-4-5 as "not sure" and 6-7 are as "agree". And then all questions and the responses gathered from the participants are explained in detailed.

LSQ	Number (%) that disagree	Number (%) that not sure	Number (%) that agree
Q9. Do you think students would reflect positively and enjoy exploring the virtual environments and interacting with the game characters?		6 (66.67%)	3 (33.33%)
Q10. The game aims to increase the ability of the		5	4

students in performing a Life Cycle Assessment (LCA) competence. Do you think playing SGM Serious Game and reflecting on their experience will help students learn about performing LCA?		(55.6%)	(44.4%)
Q11. The game aims to increase the ability of the students in Information Gathering competence. Do you think playing SGM Serious Game and reflecting on their experience will help students learn about Information Gathering?	2 (22.22%)	3 (33.33%)	4 (44.45%)
Q12. The game aims to increase the ability of the students in Decision Making competence. Do you think playing SGM Serious Game and reflecting on their experience will help students learn about Decision Making? (1 participant stated that he cannot evaluate this)	1 (12.5%)	4 (50%)	3 (37.5%)
Q13. Do you think the knowledge acquired and learning outcomes achieved by your students after playing SGM Serious Game can be transferred to other situations?		3 (33.33%)	6 (66.67%)

Table 10: Results of LSQ

Q9. Do you think students would reflect positively and enjoy exploring the virtual environments and interacting with the game characters? [Learners' and Tutors' Responses Dimension]

The participants who chose somewhat agree discussed that the game needs to be more interesting, because in its current state the game is quite confusing and not so much clear to reach a good solution. And also they commented that the game algorithm is not enough to develop skills of the player while performing Life Cycle Assessment. One interesting answer stated that although he agreed that student will enjoy it, the game might not be successful for learning. The result is shown in Chart 2 below.

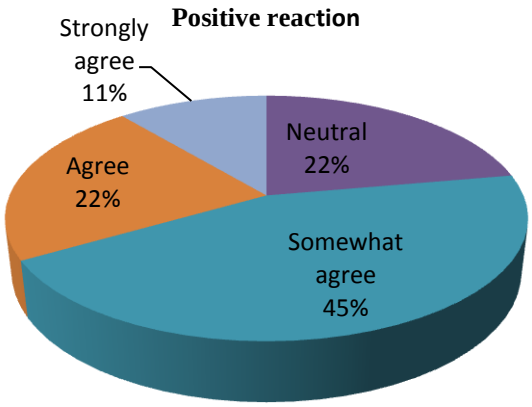

Chart 2: Positive reaction

"LCA is already complex. It is easy in the game to gather data. The game is not much realistic." (P6-Somewhat agree)

"Yes, they will enjoy but maybe it is not successful." (P3-Agree)

"Fuzzy information needs to be avoided." (P1-Neutral)

"You need to have a progress. Show some lights (red & green) when you run out of time or going on the right way." (P1-Neutral)

"I agree but it depends on personal ideas of students." (P4-Agree)

"It needs to be more interesting. It is a bit confusing not so much clear to reach best solution." (P2-Somewhat Agree)

"SGM is a nice game but it is not developing skills, game algorithm is not enough. The interface and how the game functions might be good but I do not think that it will be enough because this game do not satisfy what it promises to students, teaching LCA." (P7 - Somewhat agree)

"I will go neutral for this because according to me it depends on the character of the students. For example girls can be bored with such a game quicker than boys."(P8)

Q10. The game aims to increase the ability of the students in performing a Life Cycle Assessment (LCA) competence. Do you think playing SGM Serious Game and reflecting on their experience will help students learn about performing LCA?

[Knowledge & Skills Acquisition Dimension]

Four participants who chose "somewhat agree" stated that the game is very simple and data gathering seems easy unlike real life situations. Two teachers who selected "strongly agree" suggested that the wording dialogue tool that includes much wording

to be summarized because it makes players clueless about how to proceed in the game. The result is depicted in Chart 3 below;

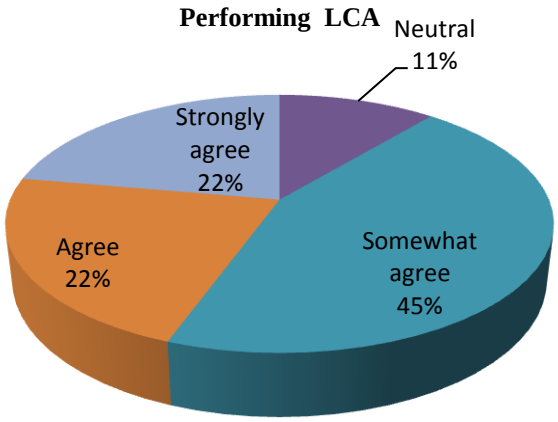

Chart 3: Performing LCA

"Data gathering seams easy and questions are already formulated. However it is not comparable to real life. Interpretation is not enough." (P6-Somewhat agree)

"If you are clueless you need to be directed to right path." (P1-Strongly Agree)

"They can first of all visualize what does it mean, get more into context rather than just seeing on the paper or listening to the lecture, and visualization helps them to understand it better." (P2 - Agree)

"This game is a virtual tool which clarifies for you the current situation inside of a factory, an office and gives insight about how you can create a connection with other characters." (P4 – Agree)

"They cannot see the all aspects of LCA, it is a really big topic. They can learn something from the game, but not comprehensive details. What is missing I think is it 114must be more comprehensive." (P7 – Somewhat Agree)

"The game is over simplified, there are too many assumptions. Assuming that you have prior knowledge I would say yes. So I say somewhat agree." (P8 – Somewhat Agree)

Q11. The game aims to increase the ability of the students in Information Gathering competence. Do you think playing SGM Serious Game and reflecting on their experience will help students learn about Information Gathering? [Knowledge & Skills Acquisition Dimension]

Answers were distributed in a long scale from "strongly agree" to "disagree". One participant, although he chose strongly agree, said that too much wording has to be

avoided in order to make information gathering more efficient. Another who chose "agree" believed that limiting players by choosing only pre-determined dialogues could decrease the learning outcome. The result is shown in Chart 4 below.

Information Gathering

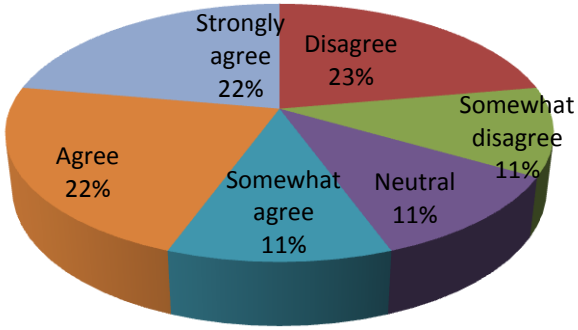

Chart 4: Information gathering

"Students do not know if the information they gather is correct or wrong, and this feature can be developed." (P1- Agree)

"Students do not know what they are looking for. Some guidelines have to be given to them about what they are looking for." (P2 – Disagree)

"Every student has his own ability to create a connection with the other guys in the game, these new tools can help them increase their abilities." (P4 – Strongly Agree)

"The dialogues are in primary school level. In the companies, you do not talk with this language. In the game it is like some sentences are taken from text books and put as dialogues. This game does not reflect the real way of communication in business environment." (P7 – Disagree)

"Information gathering seems a bit easy in the game. You just ask the question and there is an answer, more or less the same all the time." (P6 – Neutral)

"In this state of the game, dialogues are a bit, let's say cheap chat. You cannot get information from those dialogues, maybe some hints but no more than that. (P8 – Somewhat Agree)

Q12. The game aims to increase the ability of the students in Decision Making competence. Do you think playing SGM Serious Game and reflecting on their experience will help students learn about Decision Making? [Knowledge & Skills Acquisition Dimension]

Although the responses of our participants were spread among different answers, the issues they highlighted about the ability of decision making is that the game has to let students make their own decisions, in its current state of the, the game makes them collect data to put in LCA tool. So, this issue has to be reorganized in a way that students can also make decisions themselves. The result of the answers is depicted in Chart 5 below.

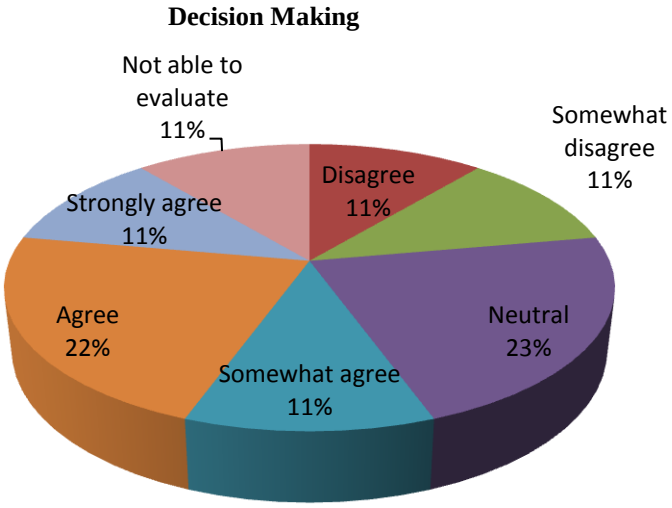

Chart 5: Decision making

"There is not a specific method to teach students." (P3-Disagree)

"The player is following the instructions gathered from characters but player has to make decisions by himself. (P6-Somewhat agree)

"I am not able to evaluate it." (P1-Not able to evaluate)

"I have to play it by myself to say something about this" (P2 - Neutral)

"At this virtual situation, students will start making decision" (P2 – Strongly Agree)

"I think that students are just following the instructions they get from the characters in the game, they do not seem to make decisions themselves." (P6 – Somewhat Disagree)

"The game seems to be mainly on decision making and then performing LCA but still it is simplified. " (P8 – Agree)

Q13. Do you think the knowledge acquired and learning outcomes achieved by your students after playing SGM Serious Game can be transferred to other situations?

[Knowledge & Skills Acquisition Dimension]

Most of teachers were agree that players will be able to apply acquired knowledge and learning outcomes by playing the game in other situation. Participants who voted to "somewhat agree" stated that in its current state of the game achieving transferability of knowledge is more difficult and it needs to be improved so that acquired knowledge can be transferable into other situations. The result is shown in the below chart.

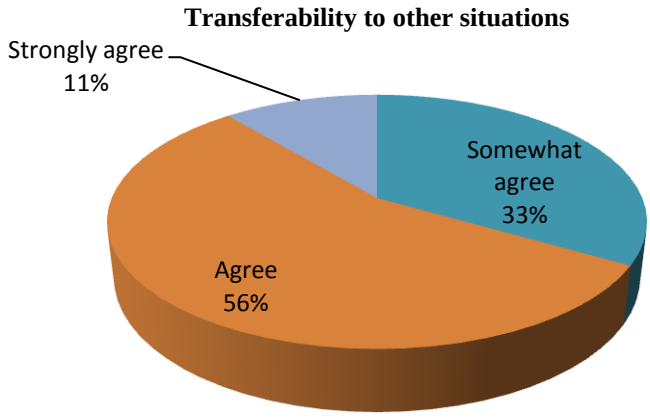

Chart 6: Transferability to other situations

"At this stage no, if it is promoted it can be transferred to other situations." (P8- Somewhat agree)

"Up to now I focused on negative points but to this question I will say yes. Because it provides a 3-D environment as a second life close to reality, you talk to people. I think it's always good to hear some theory and then to apply them in practice." (P6- Agree)

"Imagine that you will play this game a thousand times, and after that u will know how to do an LCA." (P6- Agree)

"Maybe not 100% I agree but if you improve and develop the goals." (P4)

5.2.3 Deep Questions

Q14..What do you think of SGM Serious Game as a learning tool? [Learners' and Tutors' Responses Dimension]

In this question, we tried to extract the positive and negative aspects of the game and explore whether teachers found any potential in the game so that they can be applied in the future version of the game. The negative points the participants pointed out were like the following;

"Lack of information about the logic of some algorithms, students do not know anything about how the normalization of impact categories is done." (P1)
"Measurement of results does not exist in the game, what should do student to after computing LCA? Would not it be better if they were able to discuss results they obtain with other characters?" (P1)
"During game play, students do not get any feedback about their performance. This may cause a loss of time for them."
"..lack of clear goals and directions." (P2)
"These are all pre-defined questions but not your own questions." (P3)
"You cannot write your own questions. CPA measurements have to be developed." (P3)
".. try to add some extra options in roles to let the student to define their roles by themselves." (P4)
"Too much wording in context occurs and distracts students." (P5)
"There is no learning objective in it and player is not engaged." (P5)
"Goals and results have to be matched, this is missing." (P6)
"You get the answers too easy from people!" (P6)
"When you start the game there should be more about the goal and scope definition of the game. The answers might be different according to your goal." (P6)
"Currently students cannot interact in the game by writing their own questions and find solutions. And current communication tool is very basic and not comprehensive. It affects decision making and information gathering skills negatively." (P6)
"..very basic communication not comprehensive." (P7)
"There is not a logic of choosing questions and answers. Have you ever seen a CEO who is green and sensitive? I have not seen one. They want to talk about money." (P8)
"An indication for the level of trust created between characters has to exist, it does not happen only by trying to finding the correct dialogues in a few attempts." (P8)
"Maybe normalization should be explained a bit to the students." (P8)

Although we have reached previously stated negative points, our research indicates that SGM Serious Game has positive points as well and future potential to be used for learning. The positive points gathered from teachers' interviews can be stated as;
"Students are getting familiar with a new concept of learning." (P7)

"The overall game puts students in real life context although it does not work properly with all the functions but still it s much better than just sitting in the class and listening or reading a book about it." (P6)

"It can be easier to build some knowledge about a subject that students do not know before." (P3)

"Although the game is not working well, the real life cycle context can be introduced to students and students can have the chance to start learning how to deal with different points of view." (P6)

"Visualization, interaction, and the entertainment might result positive results in learning."(P2)

"It has a great role to improve the attendance's skills in making communication." (P4)

"I like the way that they want to put this MRP/ERP system in the game." (P8)

Q15.What do you think about the future potential of SGM Serious Game as a learning tool? [Learners' and Tutors' Responses Dimension]

All nine participants have agreed that SGM Serious Game has a potential to be an effective learning tool for introducing life cycle assessment concept and how it is performed. However, for the current state of developed game, they had additional comments, both negative and positive, as the following;

"Yes, it could be a good exercise for dummies, I mean students. But I cannot use this with companies right now because there is nothing new for them." (P5)

"It has a good potential." (P1)

"..can be used as an assignment after class." (P2)

"I think it is a nice way but there is a long way to go." (P8)

"This game has the main goal to improve students' capabilities." (P4)

"If it is complete you will have a really good game about how to conduct an LCA!" (P6)

"If you improve the game for sure it will be useful for both students and teachers. But right now playing such a game is of course better than playing it however it will not be so helpful for a teacher" (P3)

"If the algorithm behind, I mean details of LCA is improved, it can be a very good tool to be used in the lectures. Because when you talk about LCA in a lecture, not many students understand it." (P7)

Q16. Do you think that playing SGM Serious Game will facilitate learning for your students? Why / why not? [Learners' and Tutors' Responses Dimension]

All teachers stated that SGM game can facilitate learning if existing problems to be repaired (e.g. dialogue tool, LCA report, etc.) and missing points(flowcharts, CPA, etc.) to be added.

"It will present clear picture while assessing themselves." (P9)

"Students learn how to conduct LCA" (P5) "Somehow yes, ..much easier to understand by being the part of the concept" (P3)

"Absolutely it will." (P8)

"Yes, if new options are provided to let them create their own rules in the beginning of the game." (P4)

"Yes, but now it is difficult. I would say absolutely if we had more time" (P6)

"Yes, somehow, but they have to be familiar with this topic." (P2)

"Although students are used to play a lot of computer games, they are not used to play games in a class. This can be useful for them." (P7)

Q17. Would you like to use SGM Serious Game in your classroom? Why/why not? [Learners' and Tutors' Responses Dimension]

Most of teachers stated that they will use the SGM game in class if they can access to all part of the game and not just some parts.

"Right now, it is not very desirable. It has to be improved and definitely it will be used." (P3)

"If it is finalized without negative points…" (P1)

"It provides a feedback for both sides (teacher and student)." (P9)

"I would use it but it must be difficult to implement." (P6)

"Yes, but it maybe is difficult because of time limitations because I have other things to teach as well." (P6)

"If it is in my area of teaching, in the future of course." (P7)

Q18. Do you think that context affects learning? What is the typical context of learning for your students? E.g. do they work mostly at home or at university? [Modes of Implementation Dimension]

"It does! And it is quite individual to say something for my students!" (P8)

"Absolutely! Where you start learning, how you work. Environment is so important; studying in the kitchen of your place when you have your friends around you is completely different then studying in a library with a 3D game." (P6)

"I think they mostly learn during the oral exam!" (P5)

"If it is not confidential, students should play the game themselves at their homes as well and explore different solutions, ways." (P7)

Q19.To what extent SGM Serious Game will be useful for students whose backgrounds are from different disciplines? E.g. do you think that students with prior knowledge about LCA and students who do not have prior knowledge about LCA can have the same knowledge after playing the game? [Knowledge & Skills Acquisition Dimension]

Six teachers believed that after playing SGM game students might reach the same level of students who have prior knowledge about LCA although the effort they have to spend can change from one student to another one. However, three of them stated that with too many assumptions in the game as it is right now, it will be difficult for a student who does not have prior knowledge to reach the same level with the other one.

"for ones who does not have an idea might start in an unpleasant way." (P3)

" ..at the end the ones with prior knowledge will have higher rank." (P3)

"They might have the same level of knowledge at the end." (P1)

"Absolutely yes, if they simplify the wordings it will be useful. Even if somebody who does not have idea about LCA can play this game and understand things and somehow changes his behavior." (P5)

"Useful for both. Students who do not have prior information can learn the concept in an enjoyable way. For the ones who had idea about LCA before, it s a good opportunity if they could not have the chance to apply it in the field. And I believe that level of learning will be different. The ones who had prior knowledge will have a higher level by playing the game. (P3)

"With these assumptions, no! They have to know so many things before playing the game! If these assumptions are relaxed, I will totally say yes!" (P8)

"No. I think if you do not have a knowledge about the topic it is not possible" (P2)

"In my opinion; no, a student who has prior knowledge can play it better than the one who doesn't have a prior knowledge. At the end, they might have the same ideas." (P4)

"The game has basic information, it can be understood by all students. You can even have this game played in Bachelor classes." (P7)

"It can be applied to more than one specific discipline and if the student is interested he can play no matter what his background is. I think broadly applicable."(P6)

Q20.How can your students use SGM Serious Game platform most effectively? E.g. playing SGM game in groups or individually, in classroom or at home. [Modes Of Implementation Dimension]

Four participants stated that playing SGM Serious Game in groups in a classroom environment can provide more considerable learning outcomes in comparison the situation where student play alone, they believed raising different ideas and thoughts in a group can make useful discussion among players. In contrary, five teachers stated that playing SGM game individually will be more preferable because students need to find different solution by themselves which might be more challenging. However, one of these participants stated that although he thinks that players should play the game as a single player, in the future when the shortcomings of the game to be redesigned it will be more useful to be played in group.

"About the place I think in classroom is better! Playing in groups would be helpful and maybe the final results will be better than playing single, but also playing single is challenging for students, and it might increase the learning level while you are trying to overcome the challenges." (P3)

"In groups, because in real projects in manufacturing they will be in a team." (P8)

"It is absolutely more effective in teams, because different people have different ideas. Maybe the game can create an environment where students can discuss answers and probably that is the most important thing that can be made in this game."(P5)

"I think they have to play in single players, but they must compete with each other because competing makes it more interesting and interactive. The place depends on the time of the class" (P2)

"It depends on their personality." (P4)

"Normally games should be played in groups but for this one maybe it is not so convenient to play in groups because it is a really basic game." (P7)

"My approach is to do it in groups, a combination of different disciplines might be interesting and more effective. CPA analysis can be interesting in this case." (P6)

Q21.Do you think game briefing/debriefing can be used to reinforce learning outcomes for SGM game? [Modes of Implementation Dimension]

All stated that briefing/debriefing session is one of the most important parts of a new application such as educational serious games it would be used for sure to enhance learning. They totally believed that a student has to know what (s)he is going to do as a sustainability manager in that virtual company and what are the objectives and goals of SGM serious game and students must be provided with all necessary information to clarify all questionable points and as a result an increase in the effectiveness of their game play experience might be achieved. Also they agreed that discussions made and feedbacks gathered during the debriefing session certainly will enhance the learning outcomes.

"Totally, both are important! If you don't have that much background, that would be nice to introduce them and after the game to get their reflections. Briefings might be shorter and debriefings might be longer." (P8)

"Debriefing is the most important part of this process! The "aha" effect of students have to created! They have to understand something!" (P6)

"Simply yes, it is important" (P3)

"Exactly! It is like teaching in the class to get a 30!" (P1)

"Absolutely! That s the most important thing! This is related with tradeoff. People do not have time, there has to be a very good briefing, that is where they learnt most. Because whenever they play sometimes they might not know why they are playing it. So what is the logic behind, what is the experience, and so on, it is very important." (P5)

"Yes, I think that is very necessary. Without that, game would be useless." (P2)

"That it is a must!" (P7)

Q22. What level of fidelity and immersion has been used in SGM game to support learning activities and outcomes? [Creation of Commitment Dimension]

Seven teachers stated that the game could not provide a situation where players immersed in the activity and the level of fidelity and immersion is low at SGM serious game. One stated the he is neutral and highlighted the lack of considerable entertainment level in the game. And last one of them stated he has not any idea about this issue.

"I don't have an answer to it, depends on the students, each student can perceive it differently" (P8)

"It creates a connection but it s not so much that it absorbs you, it is not enough." (P3)

"If complexity is enhanced a bit more I would say that fidelity and immersion would occur more and also level of entertainment is low." (P6)

"Educational games are completely different than entertainment games. Fidelity, immersion, flow are mostly entertainment games' measurements. I think educational games somehow cannot have all of these things. Because as I have said, you have to make these games simple. People who are designing educational games are not graphics/gaming engineers or psychologists but usually researchers like me so there is a gap between the games in measuring these features. And educational games are not usually well designed to have all these things. So in this game we have seen, this things does not exist that much." (P5)

"To get more involvement, there must be more challenge about how to deal with different characters" (P1)

"It is very low. Because you achieve the goals very fast. In games, you need to create levels. Maybe in this case, production level first and then the whole company." (P2)

"No, this game does not provide this features because in this state of the game a student will play the game just once because everything is predefined, questions and answers are always the same." (P7)

Q23.Do you have any comments / suggestions which you think are missing in this interview?

There were not any special comments or suggestions, but most of them highlighted again that they are interested to access the playable version of the game so that they can decide how it can be integrated into the industrial engineering curriculum.

5.3 Summary of Evaluation Questionnaire Answers

The results identified that only one of the participants had applied serious games in his teaching plan before, even though all the others applied different types of learning technologies such as power point, educational videos, simulation software and online education websites. However, all participants believed that application of serious games could have various positive impacts on learning outcomes in engineering and business schools and in this case, sustainable manufacturing.

Evaluation of effectiveness of the game was conducted in nine semi structured interviews with the participation of 9 teachers. Most of the teachers stated that the game

has a high level of interactivity and clear goals (6 out of 9), while only 1 stated that the game could reflect a real imagination of manufacturing environment. Moreover, just 3 of them accepted that it is an enjoyable environment, where students have the possibility to be able to improve their communication skills in interacting with non-playable characters (1 "strongly agree" and 2 "agree") and 7 participants believed that the game present low level of immersion and fidelity. Most of the teachers were not sure whether students' ability to perform LCA will be increased after playing the game (4 "somewhat agree" and 1 "neutral"). Following this issue, 6 of them believed that students who do not have any background about LCA will be able to reach the same level of students who have prior knowledge. On the other hand most of the teachers supported that the ability of information gathering will not be enhanced by playing the game (1 "somewhat agree", 1 "neutral", 1 "somewhat disagree" and 2 "disagree"). Also the game will not be able to improve "decision making" skill based on participants' responses, where these are 2 "neutral", 1 "somewhat disagree", 1 "disagree" and one teacher expressed that he is not able to answer this question since he could not evaluate this competence in the game. In versus, 6 out of 9 participants agreed that students will be able to transfer their knowledge and skills achieved into other situations after playing the game. There was a consensus among teachers that the game has a strong potential to be applied in class and also facilitate learning only if the existing bugs to be repaired and shortcoming elements to be added properly. In the situation where a complete game will be accessible, surprisingly, only four teachers believed that playing the SGM game in groups in a classroom environment can provide more considerable learning outcomes in comparison the situation where student play alone. Five who preferred individual playing believed that in this way students face more challenging situations and it will make them able to explore more knowledge and skills.

6. CONCLUSION AND DISCUSSION

This chapter summarizes the conclusions, discussions and the future directions for the work that is conducted and explained in detail in the previous sections of this study. Our study starts with two research questions regarding: if serious games may be a new learning tool in sustainable manufacturing education, and how effectiveness of a serious game can be evaluated. Each question is discussed as the following.

6.1 Serious Games as a New Learning Tool in Sustainable Manufacturing Education

The question of "Do serious games have the potential to be used in sustainable manufacturing education?" attempted to find the evidences why sustainable manufacturing education becomes important and how serious games could be used as a new effective learning tool while teaching sustainable manufacturing issues. Accordingly, a literature review was conducted to identify these points.

In the literature, it is discovered that sustainable manufacturing concept is becoming an important approach for today's world. Because the amount of scarce natural resources are decreasing but demand for them is increasing in the opposite direction and manufacturing industries can be shown among the ones which have the highest impact on this result. Cerinsek et al., (2011) indicates manufacturing industries comprise considerable part of global consumption of reserves and production of waste and when we look global energy consumption of manufacturing industries, it increased by 61% from 1971 to 2004 and comprise almost one third of today's universal energy consumption (OECD, 2010). While these facts exist about manufacturing industries, the term sustainability emerges and it stands "for meeting the needs of the current generation without compromising the ability of future generations to meet their needs". Since this issue requires a universal care, it becomes very important to inform people who are the consumers, and especially people who work in manufacturing industries or students who are expected to be shaping the future and may have an impact in manufacturing in a sustainable way. Thus, the education of sustainable manufacturing comes into prominence.

Dolinsek et al., (2011) states that it is essential to modify university engineering programs to meet the demands of sustainability prospect in manufacturing. Research shows that in sustainable manufacturing area, currently there exists a difficulty in

applying the theoretical knowledge in practice and how to educate. Therefore there must be some changes in how sustainable manufacturing education is being taught so that effective learning may occur for the learners.

This need literature underlines starts a new research to figure out how learning can be more effective and the findings support that today's learners are in need of a new learning tool different from traditional approaches and this can be provided with games which offer learners an engaging environment where they can acquire knowledge and retain the knowledge they acquire by experiencing it. Accordingly, literature reaches to the conclusion that serious games which are computer games with an educational objective are being used in various learning areas and they have the potential to be used in manufacturing education, as well as sustainable manufacturing education because they can facilitate the acquisition of not only technical skills, but also soft skills like collaboration, creativity and communication of the learners and fill in the gap that exists in manufacturing education area as a missing connection between the theoretical knowledge and practical experience.

Considering the growing number of projects which aim to develop serious games in manufacturing field and the companies such as Volvo Group which is already taking into account serious gaming to apply them to facilitate learning of their workers about sustainable manufacturing, we conclude that serious gaming has the potential to be used in sustainable manufacturing education.

6.2 What are the existing evaluation frameworks in literature and how can effectiveness of a serious game be evaluated?

This research question was emerged because of the results obtained from the literature about the lack of empirical evidence of games' effectiveness. The prevailing view was that all instructional games are not successful and to be able to decide if deploying a game into teaching curricula will facilitate learning, there is a strong need to conduct and an evaluation process.

Accordingly, a literature review is conducted to point out the frameworks that exist in the literature and the following studies are addressed; de Frietas and Oliver (2006), Kirkpatrick (1994), Hainey (2010), Tzu and Hung (2011). Interpreting and bringing together the features that are encountered in these studies, an evaluation framework that can be used to assess the effectiveness of a serious game is developed being composed

of five different dimensions each one having different measurement criterions. This developed framework is believed to be a useful support for researchers who aim to assess the effectiveness of an instructional serious game. The framework can also be used as a complementary tool for the redesigning phase of a serious game because it has the strength to specify what points are missing in the game application design.

As it is stated before serious games have the potential to be used in sustainable manufacturing education but without an evaluation study it is not possible to claim that a game application really facilitates learning. In this direction, an evaluation study of an existing serious game application planned to be performed. The results of the literature review shows that, there are not many serious games developed for sustainable manufacturing education objective and Sustainable Global Manufacturing (SGM) serious game included in TARGET Platform is being developed as a solution to fill in this gap. Both for its potential to fill in this educational gap encountered in sustainable manufacturing serious game field, and also to make contribution to its development phase since it is not a fully completed game yet, an evaluation study of SGM serious game is conducted in this study. Accordingly, a qualitative evaluation questionnaire (see Appendix A) is prepared based on the evaluation framework that is developed in this research and the evaluation sessions are held in an individual semi structured format with a number of nine teachers who are mostly teaching in sustainable manufacturing field. The focus of our evaluation study is decided to be on teachers' perspective because teachers are the most influential persons as they have the final decision to deploy a serious game application in their teaching curricula. Since the game is still being developed, a game presentation video to fully reflect its all features have been prepared and presented to teachers who participate in this study before conducting the evaluation session.

In conclusion, the results of the evaluation sessions demonstrated that when its development phase is completed, teachers consider SGM serious game as an alternative teaching method which they can use in sustainable manufacturing course. Positive points of SGM game stated by teachers are that it may help students to improve their social, negotiation and communication skills; introducing the basic concepts of LCA for students who do not have any prior knowledge about it. Evaluation study answers pointed out the following prominent redesign recommendations for the designers of

SGM serious game to increase its effectiveness as a new teaching and learning tool once its development phase is completed.

- The game needs to present a more complex manufacturing environment.
- Objectives and rules of the game must be stated in a clearer way.
- Instead of predefined questions and answers, students must be able to write their own questions and unnecessary dialogue options must be removed.
- Information gathering process must be more difficult and more challenge must be provided.
- Feedback mechanism must be improved and students must be able to control their performance better, measurement of results must be improved.

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APPENDIX A: Evaluation Questionnaire

1 Age: **Gender:** F / M

2 How many years have you been teaching:

3 Could you briefly describe your history in working / teaching Sustainable Manufacturing and/or Lifecycle Assessment (LCA)? E.g. How many courses do you teach, how long do they run for, etc.?

Please explain:

4 Do you normally use technology to support you while teaching? Please describe.

Please explain:

5 Have you ever used role-play to support your teaching? Please describe.

Please explain:

6 Do you play computer games in general and how do you think games can support learning? E.g What type of games do you play, sports, strategy, war, etc? Please describe.

Please explain:

7 How would you describe, explain the use of Serious Games in edutainment and how they affect learning?

Please explain:

8 Which of the following game attributes you think the SGM serious game has? (You can choose more than one)

- o Rules/Goals
- o Sensory Stimuli
- o Imagination
- o Challenge
- o Control
- o Interactivity

Please explain:

9 Do you think students would reflect positively and enjoy exploring the virtual environments and interacting with the game character(s)? (Choose only one)

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neutral
- o Somewhat agree
- o Agree
- o Strongly agree

Please explain:

10 The game aims to increase the ability of the students in performing a Life Cycle Assessment (LCA) competence. Do you think playing SGM Serious Game and reflecting on their experience will help students learn about performing LCA? (Choose only one)

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neutral
- o Somewhat agree
- o Agree
- o Strongly agree

Please Explain:

11 The game aims to increase the ability of the students in Information Gathering competence. Do you think playing SGM Serious Game and reflecting on their experience will help students learn about Information Gathering? (Choose only one)

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neutral
- o Somewhat agree
- o Agree
- o Strongly agree

Please Explain:

12 The game aims to increase the ability of the students in Decision Making competence. Do you think playing SGM Serious Game and reflecting on their experience will help students learn about Decision Making? (Choose only one)

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neutral
- o Somewhat agree
- o Agree
- o Strongly agree

Please Explain:

13 Do you think the knowledge acquired and learning outcomes achieved by your students after playing SGM Serious Game can be transferred to other situations? (Choose only one)

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neutral
- o Somewhat agree
- o Agree
- o Strongly agree

Please Explain:

14 What do you think of SGM Serious Game as a learning tool? What are positive and negative points according to you?

Please Explain:

15 What do you think about the future potential of SGM Serious Game as a learning tool?

Please Explain:

16 Do you think that playing SGM Serious Game will facilitate learning for your students ? Why / why not?

Please Explain:

17 Would you like to use SGM Serious Game in your classroom? Why/why not?

Please Explain:

18 Do you think that context affects learning? What is the typical context of learning for your students? E.g. do they work mostly at home or at university?

Please Explain:

19 To what extent SGM Serious Game will be useful for students whose backgrounds are from different disciplines? E.g. Do you think that students with prior knowledge about LCA and students who do not have prior knowledge about LCA can have the same knowledge after playing the game?

Please Explain:

20 How can your students use SGM Serious Game platform most effectively? E.g. playing SGM Serious Game in groups or individually, in classroom or at home.

Please Explain:

21 Do you think game briefing/debriefing can be used to reinforce learning outcomes for SGM game?

Please Explain:

22 What level of fidelity and immersion has been used in SGM Serious Game to support learning activities and outcomes?

Please Explain:

23 Do you have any comments / suggestions which you think are missing in this interview?

APPENDIX B: An Example of a Winning Story Dialogue in SGM Serious Game

Mark: Hello

Davida: How are you?

Mark: What do you think about the current economic situation?

Davida: The crisis is over, everyone is happy!

Mark: Why than do you want to introduce sustainable manufacturing?

Davida: We want to try out sustainable manufacturing in order to gain more market shares in the future!

Mark: I'm trying to define the boundaries of the lca.

Davida: Ok, thanks for informing me.

Mark: Could you support me with defining the boundaries?

Davida: I can help you.

Mark: What boundaries should i choose for the lca?

Davida: You should not focus on any specific part of the lifecycle but cover the whole lifecycle of the product.

Mark: Why focusing on the whole lifecycle? It is a huge effort.

Davida: The whole lifecycle is important to us in terms of the coffee machine.

Mark: Ok, thank you for the advice.

Davida: You're welcome!

Mark: Hello

Christopher: How are you?

Mark: How is our competition behaving?

Christopher: Our competition is investing the money in their production process and therefore they are contsantly improving it. And i think we should follow the same logic.

Davida: Do you want to tell me more about boundaries ? I don't have the whole day you know?

Mark: Hello

Christopher: Hi

Mark: How is the production running in general?

Christopher: It's running smoothly, because the right man is running it.

Mark: Do you think that the production process can be improved?

Christopher: That's always possible...

Mark: Ceo hired me to conduct the lca.

Christopher: Yes, yes, i know that, but frankly, it is me who will have the final word, believe me.

Mark: Can you give me some data i need for the lca.

Christopher: I can try, what are you interested in?

Mark: What should i include in the flow chart for the lca?

Christopher: Ok, i can help, but did you already set the boundaries?

Mark: Yep boss, i've done it!

Christopher: Ok, i suggest you include polyprophilene, glass, copper, steel for the assembly of coffee machine and paper for filter production. Anything else?

Mark: Thanks for now.

Christopher: No problem, if you need anything else you know where you can find me. Which specific data are you looking for?

Mark: I need the data for the inputs.

Christopher: We need 16,5 km for the transport of the material, we need 7,3 kg of wood for the paper. One coffee machine consumes 100 filters and 1,35 mj of electricity throughout its lifecycle. You should ask the shift manager or check the shop floor to gather the other data. Anything else?

Mark:Thanks for now.

Mark: Hello

Klaus: Hi

Mark: Could you provide me some data i need for conducting the lca?

Klaus: Ok, what's on your mind?

Mark: I need the values for inputs and outputs.

Klaus: Yes, i understand what you need. Let me see. For 1 coffer machine you need: 0.1 kg of aluminium, 0.08 kg of copper, 0.4 kg of glass, 4 mj of heat, natural gas, 1.2 kg of injection moulding, 1.14 kg of polypropylene, 0.125 kg of polyvinylchloride, 0.15 kg of steel, 7.3 kg of paper, wood containing, 100 of coffee filters and 1.35 mj of electricity. You transport that over a total of 16.5 km.

Mark: Thanks.