MULTI-CRITERIA ANALYSIS FOR THE DEVELOPMENT OF ONLINE SIMULATION GAMES IN LEAN SIX SIGMA

by

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ABSTRACT

SANDEEP KRISHNAKUMAR. Multi-criteria analysis for the development of online simulation games in Lean Six Sigma (Under the direction of Dr. ERTUNGA C. OZELKAN)

While online learning practices have been increasing over the past few decades due to its time and location flexibility, there has been some criticism of its lack of student engagement and involvement in comparison to the face-to-face or traditional classroom learning practices (Atchley, Wingenbach, & Akers, 2013). One particular approach that is widely used for active learning in a face-to-face classroom environment is simulation games. These games help to demonstrate a system or an industrial process in a controlled environment. Recent research showed that, while there are quite a few face-to-face simulation games in the area of lean six sigma, online counterparts are missing in most part. The research in this thesis aims to fill this gap by providing a multi-criteria decision making design and development methodology to create online counterparts of simulation games. The end-user (student) preferences are captured using Analytical Hierarchy Process (AHP), which is further analyzed using a Quality Function Deployment (QFD) methodology to understand the technical features that are relevant to a good simulation game. Using these results an online prototype for an existing lean six sigma simulation game (namely, the Lampshade Game for Lean Manufacturing) has been developed and evaluated again using a multi-criteria decision making framework. In general, the validation results from the newly developed online prototype for the Lampshade Game show that the proposed multi-criteria design methodology can be useful for developing online simulation games.

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CHAPTER 1: INTRODUCTION

Learning as a phenomenon is not restricted to a classroom but happens everywhere. It can be broadly defined as "Measurable and relatively permanent change in behavior through experience, instruction, or study" (Atkinson & Siew, 2013). Teaching is considered as imparting or transferring knowledge into students, of any age group as an attempt to empower students to learn autonomously by providing essential resources like support and feedback for that learning. Education can be considered to be built of two basic components: teaching and learning, which should be well balanced and complemented. Deep learning occurs when a student finds the learning material interesting and becomes engaged beyond the minimum requirement to complete the task. This learning is lacking in the traditional way of teaching where the student is placed in the passive role rather than an active role, which hinders the process. In contrast, interactive methods like discussion, problem-solving sessions etc. allow the instructor to influence students where they are actively working with the material. One such learning method is the education through simulations. A simulation is an imitation of the operation of a real world process or system over time (Baker, 2013). In order for a simulation to function, a model has to be developed. This model will represent the system, whereas the simulation will portray the operation of the system. The purpose of this research is to understand this system or process and develop a prototype for the simulation based on the findings in the area of lean six sigma.

Simulations are being used in a wide range of applications from safety engineering to video games. It can show the courses of action and its outcomes in scenarios where the real system cannot be engaged, because of its inaccessibility or due to danger. A computer simulation brings the real life scenario into a computer in front of the learner to experience, study and analyze it. It is also being used in a spectrum of applications like the training of civilian and military personal, healthcare, engineering etc. But its place in the education domain has been gaining importance gradually. Simulation games, as opposed to other genre of video games, portray or simulate an environment accurately and hence it has gained its place in education. Business simulations/games have been used for many years in company personnel training, development and university education (Siewiorek et al., 2012). The internet has been able to provide environments for education, business and other domains in contrast to the traditional or face-to face games to remove some of the limitations in temporal, spatial and cost aspects. The world wide web (www) and the email has also played a key role in the growth of internet to bring these elements together. Hence, the internet and www offers the educators and businesses, opportunities to explore and increase the gaming experience.

The need for an online based simulation game can be answered by investigating the number of students enrolled online and the trend this enrollment is following. Nationwide, online enrollment rates are increasing at much faster pace than traditional classroom enrollment growth; specifically, in higher education, online enrollments have grown 21%, while growth for traditional classroom instruction lists only 2% since 2002 (Allen & Seaman, 2007). In comparison to the previous years, 3.4 million college students are engaged in fully online programs for the year 2014, which represents almost 17 percent of all college students (Clinefelter, 2015). Even though the rate of growth in the near future may will not be as rapid as the previous years, the number of students seeking online education still is expected to increase from year to year. There are a few predictions that the online enrollment will make up close to 25 percent of all students by 2020 (Ginn & Hammond, 2012).The percent of colleges offering online education has also increased: more 1,200 online degree programs are being offered in the US which is 20 percent more than the previous year (Haynie, 2015). According to the Nielsen active Gamer Study (Greitemeyer & Osswald. 2008), the age group among male users has expanded significantly in the 25-40 age group. This shows the market of games in the adult range. Also the gender of the users for casual online puzzle style and simple mobile cell phones games is almost equal among males and females: according to Entertainment Software Rating Board (ESRB), almost 41% of PC gamers are women (Guy, 2007). In comparison to the scenario 20 years ago, adults, and more specifically, women are more interested towards games. In 2011, the Entertainment Software Association (ESA) based on a study of almost 1,200 American households published the following information (Gallagher, 2012):

- The average gamer is 30 years old and has been playing for 12 years. Eighty-two percent of gamers are 18 years of age or older
- Forty-one percent of all users are women and women over age of 18 are one of the industry's fastest expanding statistic.
- Twenty-nine percent of game users are over the age of 50, which increased by nine percent in comparison to 1999. Sixty-five percent of gamers play

> games with other gamers in person while fifty-five percent of gamers play games on their phones or handheld device.

These statistics show how big the market is for games and that there is a great opportunity for growth in online game simulation for learning.

Lean is a management philosophy derived from the Toyota Production System with its elements of unique Japanese culture and practices that “made possible a commitment to quality throughout the ranks as had existed in no other country before” (Hofstede, 1991,pp. 172). These practices were in contrast to the western cultural values and practices, which were focused on individual achievements, independence, entrepreneurial spirit, and emphasis on short-term goals. The successful deployment of lean manufacturing is not just the implementation of the industrial engineering tools for process improvement but it also requires an overall transformation of its organizational structure, values, roles and behaviors. This is vital, as demonstrated by the Toyota Production System, where they were able to outperform their competitors by combing these two sides. Their approach to expect a number of failures and their insistence to make it visible was in contrast to other company practices. They stated that “Toyota is a learning organization that literally thrives on its people engaging in identifying and solving problems together” (Liker et al., 2008, pp. 37).

Problem-based learning (PBL), can be referred to as “many contextualized approaches to instruction that anchor much of learning and teaching in concrete problems” (Gijbels et al. , 2005 in pp. 29), such as “active learning”, “experiential learning, “etc. PBL approaches not only stimulate interest in the subject but also promote more knowledge transfer. Rather than teaching the concepts to the students, the focus is on providing a real life experience that will give them a true sense of engagement with the real world, and learning becomes a by-product of their engagement and motivation to solve the problem. It is in accordance with the approach stated by Brown and Duguid (2000, pp. 136) that true learning is demand driven: “People learn in response to need. When people cannot see the need for what is being taught, they ignore it, reject it, or fail to assimilate it in any meaningful way”. Successful PBL goes beyond the typical learning experience because (a) the skills required to solve the problem are acquired through an experiential way and (b) students learn more about themselves and their team mates because of PBL’s team approach

Lean production principles originated in the manufacturing sector but quickly spread their way to the service sector due to the underlying principle to achieve ‘customer value’ and reduce ‘waste’, which is the objective of almost all services. Customer value can be defined as any action, process, feature or service that a customer is willing to pay for, while waste (also referred as muda) is defined as those activities or products that do not add value to the customer. As the influence of lean production principles and tools becomes more relevant in the market, engineering and management schools started using them in their courses (Kanakana et al., 2012). For teaching lean, PBL with a focus on active learning is a more effective method than the traditional way. One way of active learning is through simulation of real world scenarios to provide the best realistic experience. . For example, students in a study by Lyckeet al. (2006) reported learning to appreciate the difficulties and benefits of working in teams, arriving at a new sense of themselves as active contributors to a group and gaining a new sense of higher expectations for others in the group (Lycke et al., 2006). Since lean emphasizes on teamwork, culture of problem solving, on learning what to focus on, value of failure, importance of learning in human development and how to practice lean manufacturing, PBL is clearly a fitting approach to learning lean concepts. Thus lean teaching using simulations and games seems to be beneficial as it is on one hand as realistic as possible but at the same time it avoids the dangers or inconveniences of the real life scenario. Presently there are several lean simulation games, some which focus on specific tools, while others aim at demonstrating certain concepts (Badurdeen et al., 2010). This research is focused on designing online simulation games that will educate the audience about the concepts of manufacturing with the main emphasis on lean.

Definition of terms:

The following terms are being used repeatedly throughout this report. Their definitions are summarized as follows:

TABLE 1: Definitions of key terms

Term	Definition
Lean – Six sigma education	Any coursework that teaches theory and practice of, or foundation topics related to Lean Six Sigma.
Online classes	Any education session that delivers knowledge via internet in the form of images, text, audio, or video, and participants are not required to have face-to-face interaction with teacher for achieving the learning objectives of that session.
Simulation	An activity that attempts to mimic a real life activity, role, or process that a participant can relate to and imagine to be a part of in the real world.
Games	Same as the definition for simulations. Additionally, it has an element of competition involved between participants or groups.
AHP	Analytic Hierarchy Process

QFD	Quality Function Deployment
Traditional/ face-to face teaching method	Teacher-centered learning methods and knowledge delivery via lectures, presentations, textbook discussions and case studies.
Online simulations	Simulations hosted in an internet platform. This can be based on graphical images, animations, or simulations using communication via text or voice using internet. Or in general, any simulation that is done via internet without face-to-face interaction of participants.

CHAPTER 2: PROBLEM STATEMENT AND OBJECTIVES

Problem statement:

There exists a gap between the face-to-face classroom teaching and online teaching (Kottayil, 2014). In order to fill this gap, one most efficient mode is through simulation games, which have gained their place in classrooms and are gaining importance in online mode of teaching. This research aims to fill the gap between face-to-face and online simulation games by following a multi-criteria decision making design and development framework to create online counterparts of two lean six sigma simulation games.

Objectives and specific tasks:

While a preliminary study was done (Kottayil, 2014) that shortlisted the design criteria and deployed the testing of the dice game at the graduate level but the sample size was low and limited. Thus based on the problem statement above and the results of prior research, the following objectives have been set by the thesis committee for the current research:

1. Enhance the literature review to incorporate relevant publications
    i. To study the previous work done
    ii. Add new publications
2. Validate student preferences for designing an online simulation game
    i. Redo the preference surveys with undergraduate students
    ii. Extend the preference surveys at the graduate level

3. Validate comparison of existing games versus proposed online games

    i. Test the existing Dice Game with the undergraduate students

    ii. Develop a new online simulation game: the Lampshade Game

    iii. Test the new online Lampshade Game with the graduate students

    iv. Test the new online Lampshade Game with the undergraduate students

CHAPTER 3: LITERATURE REVIEW

Design Criteria:

A survey was conducted in an earlier study to identify the appropriate criteria that can be used to evaluate simulation games (Kottayil, 2014). In that study, a total of 11 participants were asked to suggest any criteria they deemed to be important to the list, which also contained criteria that was found through a literature survey. From a list of criteria including substantive learning, complexity, duration, customizability, timing flexibility, fun, learning objectives, discussions, engagement level, interaction, cost, pre-requisite knowledge, key topics covered, configurability, industry settings, real-world connection, graphics, interesting topic, intuitive game play, “non-boring” duration, and different player modes. The five criteria namely, ‘Substantive Learning’, ‘Engagement Level’, ‘Complexity’, ‘Duration’ and ‘Configurability’ were found to be the most significant ones.

Online teaching:

When teaching online courses in the university level, one of the prime concerns for many teachers is how to improve student engagement, encourage communication and build a sense of community in this virtual setting, which will reflect whatever that occurs in a face-to-face classroom and more (Glazer & Wanstreet, 2011). Due to the changing nature of class discussions, student behavior and skill levels, a major challenge of teaching at higher educational level is the expertise to efficiently communicate the class material to a group of students and encourage interaction. Moreover, the factors of educational discussions, student engagement, and knowledge levels, essentially demand that teachers extemporaneously moderate the content. But how can these educational and communicative aspects that exist in the face-to-face educational mode be reproduced in the virtual classroom? There will always be differences between these two modes of instruction and learning, but in many effective ways, face-to-face educational pedagogy and practices can be redesigned to create interactive and engaging online courses.

Educational Games:

Studies of the educational effect of games on students include Wang (2010) who applied a mixed methods game study using a simulation history game. He statistically proved that students have significantly increased their content knowledge and also had a better motivation to learn. It was also found out that the basic gameplay is the core towards the design of a game. The stance taken by the designer for implementing interaction into the game is similar to the stance taken by a teacher in the classroom (Foster & Mishra, 2009a).

In real life scenarios, while playing a game or working in an industry, there are other users who perform the activities as well. In a simulation game with multiple virtual users, the gameplay and engagement level of the game increases as there is unpredictable human behavior. According to Labat (2008), these virtual users should have the following characteristics:

1. They should play in an ordinary way, i.e., not too well, nor too poorly.
2. Their gameplay should be unpredictable.

Multiplayer:

Anderson and Lawton (2009) has stated that multiuser collaborative simulations increase cognitive skills, appeal to multiple learning styles, and provide multiple modes of interaction with learning. But there is a limit to the number of users that can be allocated in the same room. This can be overcome with the use of external webservers for content delivery, and external databases to store learning assessments. Although, if the project or the game is huge, this will be impractical (Vender, 2010). By employing Non-Authoritative State Synchronization or Common Interfaces this can be tackled.

In a multiplayer game, the following requirements should be taken to consideration for a robust approach (Reuter, 2013):

- Give realistic and logical reasons for multiplayer collaboration
- Demand equal contribution by the users
- Reduce waiting times
- Encourage communication
- Include actions to coordinate

Retention in higher education:

One of the existing and long-standing issues in higher education is the departure of students (Geiger, 2010). This was recognized in American higher education since the late 1800s and its study had begun as early as 1926 (Boston et al., 2011). A number of models and interventions focused at improving retention has been suggested (Angelino & Natvig, 2009). Once enrolled, student internal factors of self-efficiency, motivation and time management along with external factors of family, course design/ relevance and organization needs to be explored (Park & Chio, 2009). A deeper understanding of these factors will help with the development of more effective teaching methods and services for online learners. It has also been agreed that student retention is a complex challenge, subject to multiple factors (Allen & Seaman, 2011; Boston & Ice, 2011). But research has shown that student engagement and involvement is directly proportional with student leaning outcomes and retention (Poll et al., 2014).

Synchronous and Asynchronous teaching:

The word synchronous means working together at the same time and the word asynchronous terms its opposite. But in online education, active student participation – whether synchronous or asynchronous- is crucial for student engagement and achievement of learning outcomes (Chao et al., 2012). In synchronous teaching, which should also use asynchronous interaction and discussion, students need to communicate directly with each other and the instructor, which is done through live virtual meetings. In order to increase engagement and participation, tools such as chat box, ability to share documents, PowerPoints, video and film clips are used (Sher, 2009). These tools will allow the teachers to deploy the same practices and pedagogy as in a face-to-face course. Small breakout group sessions through meeting software can be used to simulate small group activities as in face-to-face classroom (Kranzow, 2013). Employing such small groups not only encourages student-to-student interaction, but it also improves engagement in large group discussion following the activity.

In completely asynchronous courses, teachers should design and encourage participation in small group activities through the use of course management site by arranging the students to groups and giving clear instructions for the objectives and tasks that they are to finish together (Grinnell et al., 2012; Kranzow, 2013). In asynchronous small groups, since the students are free to schedule small interaction groups, flexibility increases. Whether synchronous or asynchronous, the foundation of any online course should be though the use of asynchronous discussion forums (Nandi et al., 2012).

Student centered learning:

Creating individual learning relationships with students that are highly infused with sensitivity and flexibility to each student's skill level, personal concerns, and obligations directly influences and improves students' likelihood to build a personal relationship to the material discussed in the course, their participation and involvement in the course activities and discussions, and their completion of the course (Ke & Kwak, 2013). Offering scheduling flexibility in completing their educational goals and degrees, is one of the prime elements in the nature of online instructions (Goddu, 2012). Hence in an online course there should be instructor flexibility not only to the students' varying from school, work and life schedules but also to unpredictable situations that may arise (e.g., emergencies, illness, travel etc.) Instructors are seen leaner-centered facilitators, in order to encourage and necessitate individual student motivation for fulfilling the requirements of the course (Smart, Witt & Scott, 2012). Also to encourage a "hands-on" student learning style in online courses, these courses can be designed learner-led activities, such as assignments, projects, presentations, small and large group discussions (Ruey, 2010). Online instruction has advantages from student-driven learning, activities and discussions that focus and fosters on student engagement (London & Hall, 2011; Ruey, 2010).

CHAPTER 4: METHODOLOGY

The research methodology is explained in this chapter by discussing the testing strategy, Analytic Hierarchy Process that is used to analyze the voice of the customer, the steps in developing the prototype and the statistical tests used. Furthermore, a Quality Function Deployment framework has also been developed to accept the critical customer requirements and translate it into its corresponding technical features, which will satisfy this requirement.

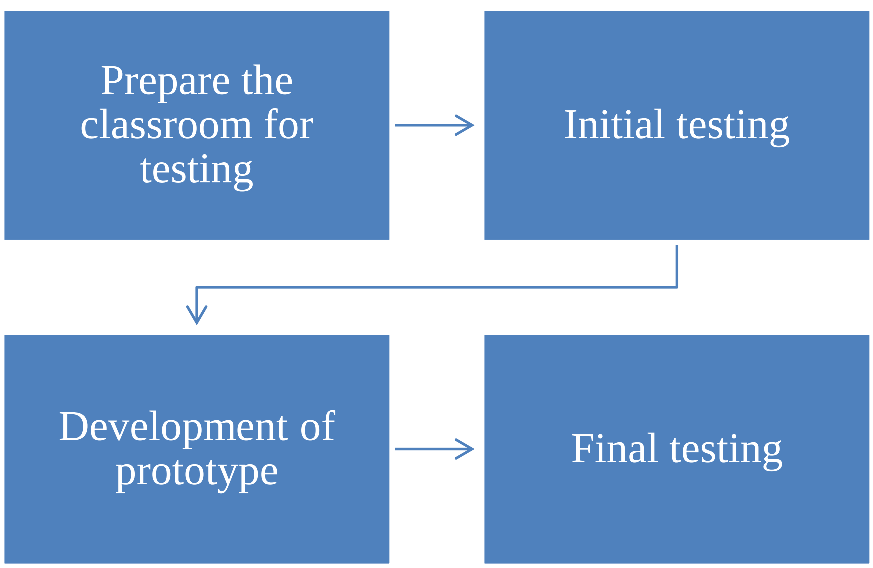

FIGURE 1: Methodology of research

1. Prepare the classroom for testing:

The population under consideration are the students of Systems Engineering and Engineering Management (SEEM) Department at the University of North Carolina at Charlotte, both undergraduate and graduate levels. The sample population is randomly chosen for participating in the tests and evaluating the criteria. The games under study are the dice game and the lean lampshade game, which require different materials and settings for playing it. Hence the appropriate arrangements are done suited to the game in both scenarios. Further explanation regarding both the games and its gameplay, has been discussed in chapter 5.

2. Initial testing:

The face-to-face classroom version of both the dice game and the lampshade game will be played for the initial testing phase. Students from the undergraduate and graduate level are the subjects under study. After playing the game, they are asked to give feedback based on the different design criteria. An excel file with the necessary instructions was provided for their perusal. This also acts as the first step in designing an AHP (Analytical Hierarchy Process), which will be explained in detail later in this chapter.

3. Development of prototype:

From the initial testing phase, student feedback on the design criteria were used to identify the ranking of criteria based on their preference. This preference was further analyzed using a QFD (Quality Function Deployment) tool, to translate these design criteria into technical features. The methodology of QFD has also been discussed in this chapter. Using the QFD as a guide, an online prototype of the lampshade game has been developed as a part of this research.

4. Final testing:

After the prototype was developed, it was played by the students (undergraduate and graduate) to compare it with the existing face-to-face classroom version of the lampshade game, based on the design criteria. This comparison will show how the new prototype has scored in contrast to the face-to-face classroom version. Feedback were also taken from the audience, on how to further improve the prototype for future versions.

Note on data collection and validation:

The proper selection of methodological design for data collection is of high significance, since there are errors, interferences, carryover effects that will hinder the actual response of the experiment. There are two possible approaches: the within-subjects design and between-subjects design. They both involve comparing two or more conditions and analyzing the effects of those conditions on one or more groups of users (MacKenzie, 2013) but in a within-subjects design, each participant is tested under each condition. So a test done by each participant under one condition (games in this case) is repeated under another condition. The alternate for this approach is a between-subjects design, where each participant is tested under one condition only. In other words, one group is tested for 'Game A' and another separate group is tested for 'Game B'.

In the within-subjects design there are two fundamental advantages: a) power and b) reduction in error variance. According to fundamental statistics, as the sample size increases the statistical power of the test increases which in turn will decrease the probability of beta error (the probability of not finding an effect when one “truly exists”) (Rideout et al., 2010). If a between-subjects design is implemented, it will lead to an increase in error variance due to the fact that, even though the assigned subjects to the group are randomly selected, the two groups may differ with regard to important individual difference factors that affect the outcome. The between-subjects design lacks in these criterions as the sample size will not be as large as the within-subjects design. With the within-subjects designs, the conditions are constant with respect to each individual reference variable as the participants are the same in the different conditions. But there is also a fundamental disadvantage with this approach, which can be referred to as “carryover effects”. The common types of carry over effects are fatigue and practice. Fatigue doesn’t play a major factor here as the games are simple and are not played in quick succession but with a certain period of time, but not so large that the participants forget the features of the game played. But as the same group is being tested for each condition there is a probability that the participant would embark upon a learning curve through practice.

Taking into consideration the pros and cons of the two methodologies, the within-subject and between-subject design has both been implemented for this research because of the mixed population scenarios. In some scenarios, the same population will be made to play all versions of the game as in within-subject design. But in other scenarios, different populations are used to play single versions of the game emphasizing the between-subject design.

Analytic Hierarchy Process (AHP):

In a decision-making process, one of the crucial steps is the accurate estimation of pertinent data (Saaty, 1980). For catching the response of multiple participants on multiple criteria, the Analytic Hierarchy Process (AHP) has been used. The AHP is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology (Saaty, 1987). It is a multi-criteria decision making tool to get the ratings of the different criteria, namely, substantial learning, engagement level, complexity, duration and configurability in this scenario. AHP generally involves four major steps in the decision-making process as shown in FIGURE 2.

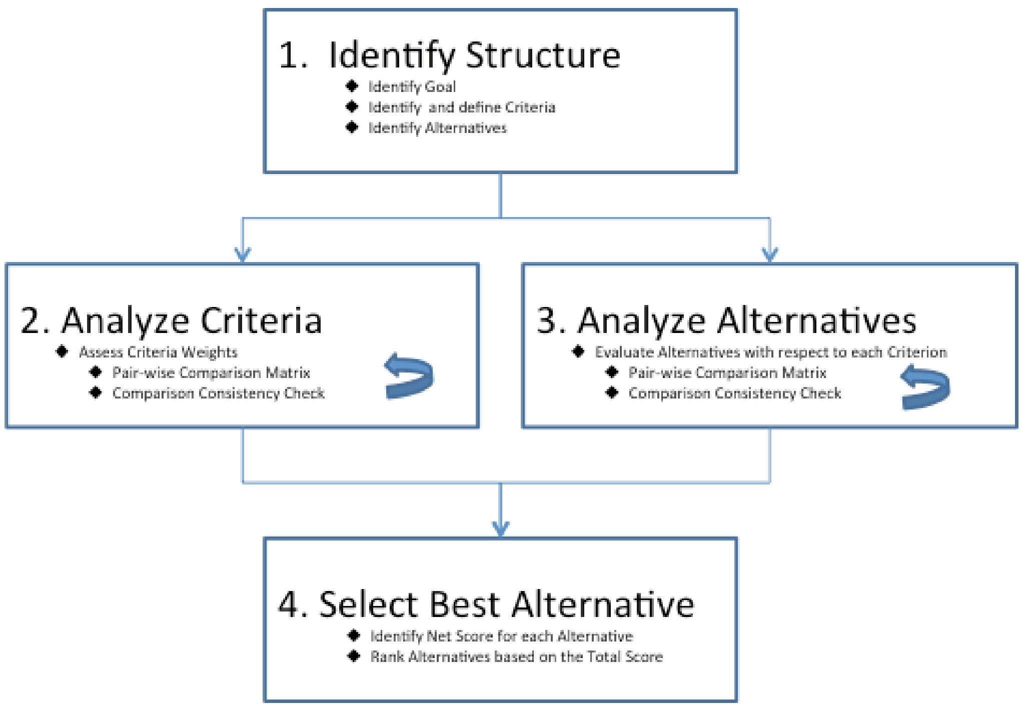

FIGURE 2: Major steps of Analytical Hierarchy Process

It can be implemented to find the ranking and weights of different criteria that target users use to evaluate educational simulations. By using pairwise comparisons of different alternatives based on each of these criteria, the alternatives can be ranked. The basic process of AHP analysis includes 1. Breaking down the problem into hierarchy of goals, criteria and alternatives; 2. Collecting pairwise comparison data for evaluating the weights of criteria. A linguistic scale between 1-9 may be provided to the user for pairwise comparisons (Reza, Sadiq, & Hewage, 2011); 3. Pairwise evaluation of alternatives based on the identified criteria; 4.Synthesis of final scores for alternatives based on its score for each criterion and the weights of corresponding criterion; 5. Checking the consistency of the judgment.

The original AHP method proposed by Saaty involves using dominant right eigenvector to find the underlying scale of ranking from a reciprocal symmetric judgment matrix (Saaty, 1990). However, a normalized geometric mean can also be an estimator for this underlying scale (Crawford, 1987; Wind & Saaty, 1980). For this project a geometric mean approach is used to synthesize the ranking and weights of different criteria. In this project, in addition to using multiple criteria, the problem is more complex since there are multiple decision makers involved as well. The consolidated criteria weights are derived from the judgments of different people as each individual responder act as a different decision maker (Saaty, 1983) has outlined two different approaches for synthesizing group judgment from individual judgments. In the first method, a consensus is reached between the individual members for each pairwise comparison. In the second method, the group judgment is calculated from the individual judgments. As detailed in the literature review section, Aczél and Saaty (1983) has found that group judgment can be synthesized for each pairwise comparison by calculating the geometric mean of individual judgments for that particular pairwise comparison. In this project, the second method is used since a substantial difference is expected between individual judgments, which would make bringing all group members together to reach consensus a difficult task. Following the process outlined by Saaty (1989), the process for finding the evaluation criteria and their respective weights is detailed as follows:

Step 1: Obtaining individual judgement

After the simulation session, the users were asked to fill the AHP template file using MS Excel, as shown in FIGURE 3.

Number of Criteria 5

Step 1. RANK CRITERIA

No	Criteria	Description	Ranking of Criteria
1	Engagement Level	This is related to the questions such as How much fun you have playing the game. How much interac	2
2	Substantive Learning	This includes number of learning objectives Subject matter, Subject topics that are covered during th	1
3	Complexity	How complex or simple is the activity. Related to questions such as does it take too much time to und	4
4	Duration	The duration of game play or simulation activity.	5
5	Configurablity	How far the game/ simulation is customisable? Are there options to configure it to specifically match	3

Step 2. PAIRWISE COMPARISON MATRIX

In the below table, please use PAIRWISE COMPARISONS, to indicate the relative importance of one criterion over another using the following scale

1 EQUAL 3 MODERATE 5 STRONG 7 VERY STR0NG 9 EXTREME

NOTE: You can use numbers in between and recipricals such as 1/3, 1/5/, 1/7 and 1/9 so show "less importance", but please do not go beyond this range!

Example: an entry of "3" in the cell corresponding to "Engagement" (row) and "complexity" (column)
would indicate that "Engagement" is "moderately" more important than "complexity in simulation evaluation
an entry of "1/3" in the cell corresponding to "Engagement" (row) and "Complexity" (column)
would indicate that "Engagement" is "moderately" less important than "complexity" in simulation evaluation

NEED MORE HELP: PLZ READ WORKSHEET NAMED "readme-example"!

ONLY FILL in the cells colored in green, DO NOT FILL THE CELLS COLORED IN RED

Make sure your comparisons are consistent with the Ranking you provided above!

		1	2	3	4	5	**Criteria Weights**
		Engagement L	Substantive Le	Complexity	Duration	Configurablity	
1	Engagement Level	1	1/3	5	7	3	26%
2	Substantive Learning	3	1	7	9	5	51%
3	Complexity	1/5	1/7	1	3	1/3	6%
4	Duration	1/7	1/9	1/3	1	1/5	3%
5	Configurablity	1/3	1/5	3	5	1	13%
						Total	100%

Notes:
The entries in bold are corrected/entered as reciprocals to reflect the ranking!

Comparison Consistency Rating: Very Good

FIGURE 3: Sample AHP template

Initially the user was asked to rank the different criteria according to the order of preference from 1 to 5. These values were not used anywhere for calculation but stand as a guide for the next step in filling the pairwise comparison matrix. This step was not introduced by Saaty in his version of AHP but it was found useful in previous projects completed under the department of Systems Engineering and Engineering Management.

Step 2: Pairwise Comparison

In the next step the user was asked to fill the pairwise comparison matrix of the AHP. The pairwise comparison is used to evaluate two criteria at a time in terms of their relative importance. To make comparisons, a standard scale was used to rank the criteria and also to indicate how many times dominant or submissive one criterion is over the other. A scale of 1-9 is adopted for this research as shown in the TABLE 2 below (Li-Mei et al., 2014):

TABLE 2: Scale for AHP

Intensity of Importance	*Definition*	*Explanation*
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *I* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.	

If criterion A is ‘moderately less important’ than criterion B, the intersection of those 2 cells is given the value 1/3. And if criterion A is ‘moderately more important’ than criterion B then the intersection of those 2 cells is given the value 3. Similarly the rest of the comparisons are done. The participants use this scale to portray their suggestions on the criteria and also to compare them. These numbers are evaluated to get a final score which will contain their opinion regarding each criterion and condition.

Step 3: Calculating the criteria weights:

The criteria weights are calculated for comparing each criterion with each other and hence to find the criterion with the highest rating following these steps:

1. Each cell in the top right diagonal half was filled by the user to enter their subjective scoring as ratio of row/column.
2. The geometric mean for each row, corresponding to a particular criterion was calculated.
3. Each geometric mean was divided by the sum of all the geometric means to normalize them.
4. Similarly, all the individual responses for the entire matrix were gathered, and steps 1 to 3 were repeated to obtain the weights of all criteria.

TABLE 3 shows an example of the AHP evaluation template filled by a user based on the design criteria.

TABLE 3: Sample of user design criteria preference

		1	2	3	4	5		
	Criteria	**Engagement Level**	**Substantive Learning**	**Complexity**	**Duration**	**Configurability**	**Geometric Mean**	**Criteria Weights**
1	**Engagement Level**	1	7	1	3	9	3.707792751	41%
2	**Substantive Learning**	1/7	1	1	3	5	1.967989671	17%
3	**Complexity**	1	1	1	5	7	2.432299279	29%
4	**Duration**	1/3	1/3	1/5	1	5	0.759835686	9%
5	**Configurability**	1/9	1/5	1/7	1/5	1	0.27494162	3%
						Total	9.142859007	100%

The user is only asked to fill the upper right triangle of the matrix, since the Excel sheet has been designed such that the lower left triangle will be automatically filled with the inverse of the upper right triangle. For example if criterion A is ‘extremely more important’ than criterion B then the intersection of those 2 cells is given the value 9 and the inverse of this case will be that criterion B is ‘extremely less important’ than criterion A and the intersection of those 2 cells will be automatically filled with a value of 1/9.

Step 4: Calculation of Consistency Ratio:

Maintaining consistency of the participant’s judgement is a fundamental factor while evaluating the AHP, as there is a probability that the participant might get confused or input incorrect value not consistent with his earlier stated opinion, which will affect the entire analysis. Hence a consistency ratio needs to be checked throughout the analysis to corroborate the logical consistency of the matrix. Logical consistency simply means that if A> B and B>C then, A>C should be true. The consistency ratio for each judgment matrix should have a value less than 0.1 to be considered as consistent. It should be noted that a hundred percent mathematical consistency is not expected. If the mathematical consistency is forced, the geometric mean obtained will be similar to those obtained through simple arithmetic mean, and the arithmetic mean does not yield satisfactory results (Wind & Saaty, 1980).

The consistency ratio is approximated by the following steps:

1. Multiply each column of the pairwise comparison matrix by the corresponding weight
2. Divide the sum of the row entries by the corresponding weight.
3. Compute the average of the values from step 2, and it denote it by $\lambda_{max.}$
4. Then the approximate consistency index is calculated by the equation

$$CI = \frac{\lambda max - n}{n - 1}$$

   Here n is the number of criteria.

5. Based on the random index value from the random index table created by Saaty, the consistency ratio is calculated as CR= CI/ RI (Saaty, 1987). If the CR value is below 0.2 then it is considered as good.

Quality Function Deployment (QFD):

After the initial testing of the classroom versions of the lampshade game, a Quality Function Deployment (QFD) analysis has been developed. A QFD is a “method to transform qualitative user demands into quantitative parameters, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts and ultimately to specific elements of the manufacturing process.” as described by Akao (1994). It was originally developed for the manufacturing sector, which later on found its place in the service sector because of its adaptability. After its introduction, it was soon utilized by companies like General Motor, Hewlett-Packard, Ford, Digital Equipment, 3M, AT&T, IBM, Kodak, Boeing, NASA, Nokia (Chan & Wong, 1994; Waurzyniak, 2005). It clearly captures the voice of the customer and translates them into specific design requirements. In this case, the customer feedback on the design criteria are taken and translated into the corresponding technical requirements for developing an online simulation game. The detailed step-by-step procedure for developing a QFD will be discussed in the next chapter.

Statistical analysis of responses:

Since in many situations it is practically impossible to collect information from the entire population, the solution is to collect a sample from the population and use this sample for analysis. After collecting the data, every data sample has to be scrutinized and analyzed. The objective of this analysis is to identify any trends or create a model that will explain the results. The statistical analysis can be broken down into the following steps

1. Describe the nature of the data to be analyzed
2. Explore the relation of the data to the underlying population
3. Create a model to summarize understanding of how the data relates to the underlying population.
4. Prove (or disprove) the validity of the model.
5. Employ predictive analytics to run scenarios that will help guide future actions.

Whenever data is collected, descriptive and inferential statistical analysis can be performed.

Descriptive statistics:

Descriptive statistics are used to describe the sample or summarize information about them like mean, variance, and standard deviation. With the data collected from the participants' feedback of the AHP evaluation of criteria responses, a descriptive statistical analysis was run.

Inferential statistics:

Inferential statistics are used to make inferences or generalizations about the broader population based on the sample data. Examples of inferential statistical methods include t-tests, z-tests, and one-way ANOVA. A one-way ANOVA analysis was used for the participants' feedback on the AHP criteria with the following hypothesis:

Null hypothesis, H_0 : The weights of every criterion are same

Alternate Hypothesis, H_a : At least one criterion carries a different weight

This ANOVA test will find if there is a statistically significant difference between weights of different criteria.

Prototype development:

A prototype was developed for the online version of the lampshade game as a part of this research. Presently, there exists only the classroom version of the lampshade game. Since this version is an initial prototype, the simulation is developed with the help of Microsoft PowerPoint embedded with visual basic (VB) macros to simulate the basic gameplay and concepts of the game. This version has been created using the existing classroom version as a template and the user feedback on the design criteria. The user feedback on the design criteria has been further translated into technical features, which will help the developer to concentrate on those features.

Testing:

For the testing phase of the research, the within-subjects design and between-subjects design methodologies were adopted. For the dice game, currently four versions are available: a classroom version, an existing online version, an iPhone version and a prototype developed by the Department of Systems Engineering and Engineering Management of the University of North Carolina at Charlotte for analysis (Kottayil, 2014). The prototype was developed with the help of the feedback received from the customers, the students. The initial testing for the dice game has already been done prior to this research. The class of SEGR 4090 – Lean Six Sigma System Design of Spring 2015, was a proper platform for the testing of the dice game due to its focus on the concepts of lean six sigma, and the game could be useful to help students to grasp the application of lean principles in real life scenarios. All the versions of the dice game including the developed prototype were played, and their corresponding reviews and comparisons were recorded with the help of AHP.

For the lampshade game presently there exists only the face-to-face version, which was also played by the class of SEGR 4090, Spring 2015. Using these results and prior tests, the online prototype of the lampshade game was developed. Even though this audience was not able to play this prototype, their general views on simulation games and feedback regarding the existing face-to-face classroom version of the lampshade game was collected. This methodology classifies as a between-subject design since one condition (face-to-face version) of the game was played by one group and the online prototype was played by another group. Even though the online game developed has been designed for a general population, these feedbacks will help in understanding features to concentrate on for the design. From the graduate level, the class of EMGT 6915- Engineering Decision and Risk Analysis (Spring 2015) played the face to face version of the lampshade and their feedback were also collected.

After the online prototype of the lampshade game was developed, it was tested at both undergraduate and graduate levels. The undergraduate class of SEGR 2101-001: Systems Engineering Concepts (Spring 2015) played this version and provided their feedback. From the graduate level, the game was forwarded to the same batch of EMGT 6915- Engineering Decision and Risk Analysis students who have played the face-to-face classroom version, to obtain their pairwise response on both the face-to-face classroom version and the new online prototype of the lampshade game. It was not given as a part of any class activity but as a voluntary activity. The online version was also forwarded to the students of EMGT 6980-081: Industrial & Technology Management Seminars (Fall 2015) as an optional assignment. The participants and their details have been summarized in TABLE 4.

TABLE 4: List of participants

Course	Level	Game
SEGR 4090 – Lean Six Sigma System Design (Spring 2015)	Undergraduate	• All 4 versions of the dice game • Face-to-face classroom version of lampshade game
EMGT 6915- Engineering Decision and Risk Analysis (Spring 2015)	Graduate	Face to face version of the lampshade
SEGR 2101-001: Systems Engineering Concepts (Spring 2015)	Undergraduate	Online prototype of lampshade game
EMGT 6915- Engineering Decision and Risk Analysis (Spring 2015)	Graduate	Online prototype of lampshade game
EMGT 6980-081: Industrial & Technology Management Seminars (Fall 2015)	Graduate	Online prototype of lampshade game

CHAPTER 5: IDENTIFY PROBLEM STRUCTURE: CRITERIA, GOALS AND ALTERNATIVES FOR SIMULATION GAMES

This chapter will explain the first step of AHP as mentioned in the previous chapter which will deliver additional findings that will be analyzed.

Identifying Criteria:

In the previous research, a thorough analysis on the design criteria for evaluating simulation games was performed (Kottayil, 2014). Initially the major criteria that appeared commonly in the literature were listed out and given to the audience for feedback. They were also asked to add any criteria which they felt were important to the list. Finally, the following design criteria were shortlisted as the major ones:

1. Substantive Learning: Includes number of learning objectives, subject matter, subject topics that are covered during the game, etc.
2. Engagement Level: Related to how much fun participants have playing the game. How much interaction participants have with other players. How good the platform for discussion and collaborative learning is. Presence of competition or race. How interactive the game design is.
3. Complexity: Importance of how complex or simple the activity is. How long it takes to understand the rules. Is the gameplay confusing?
4. Duration: The duration of game play or simulation activity. Does it take long time to achieve the learning objectives?

5. Configurability: How much the game or simulation is customizable? Are there options to configure it to specifically match manufacturing, services, healthcare? Can the number of people required for the session be changed? Does the user have the option to play in a single player or multi-player setting? Can the difficulty level be varied for different users?

Identifying alternatives:

The dice game and the lampshade game are the games under review for this research. All the existing versions and the developed prototypes are the alternatives being evaluated through AHP.

1. Dice game:

The classroom version of the dice game and lampshade game required an extensive preparation in context of the raw materials and the arrangement of the process. The dice game is a popular lean six sigma exercise introduced by Goldratt (1992) to emphasize the effects of process variability and bottlenecks on the system performance. The primary purpose of the exercise is to educate the audience about the root cause in some prominent issues in a production or supply chain environment such as high inventory, production delays, overtime and other wastes. The uncertainty or variance present in the system is simulated with the help of a die roll, which will determine the daily capacity of the workstation for production. The participants are allocated to different workstations in the production line and each participant will roll a die to simulate the day's capacity randomly. This variability will build up downstream and the production results in less than the statistically expected average if high process variability is present in the system (Goldratt & Cox, 1992).

This dice game has been modified to demonstrate the effects of variability in different production scenarios. The classroom version of the dice game involves three scenarios of the game, which are based on traditional push production system, a reduced variability system and ConWIP production system (a constant work in progress system). Apart from the existing objectives of the dice game (i.e. to simulate the uncertainty due to process variability and dependency to previous workstation stations), this version also educated the audience about push and pull production system. . An illustration of this version of the Dice game is shown in FIGURE 4.

FIGURE 4: Illustration of the dice game

The push system is the mode of production used in mass production where production is scheduled to meet the anticipated demand based on the market forecast and 'pushed' through production as quickly as possible. Whereas the pull system is the type of production system used in lean production in which production is triggered by customer order.

Face-to-face version:

The version played in the classroom as part of this study typically sets up five to seven workstations starting from scheduler to shipping, and it is played using regular dice and plastic chips. Five to ten participants can effectively be accommodated in one session. The participants need to assemble in the room at a scheduled time, which brings down the flexibility of the game session, and it takes about 2 hours to complete. On the other hand, it allows real-time discussions between the participants, fun to play in a group, and it provides a great amount of control of the game flow to the facilitator.

Existing online version:

An online version of the dice game is already available online for free, which does not have multiple iterations of the different setups. This version does not provide any configurable settings to the user. Also it does not have any multiuser options, which reduces its engagement level and the discussions related with the gameplay. However, since it is an online version, it can be played at the user's convenience by the participants at any time. Its duration is short and the gameplay is very straightforward. FIGURE 5 shows the screenshot of this version.

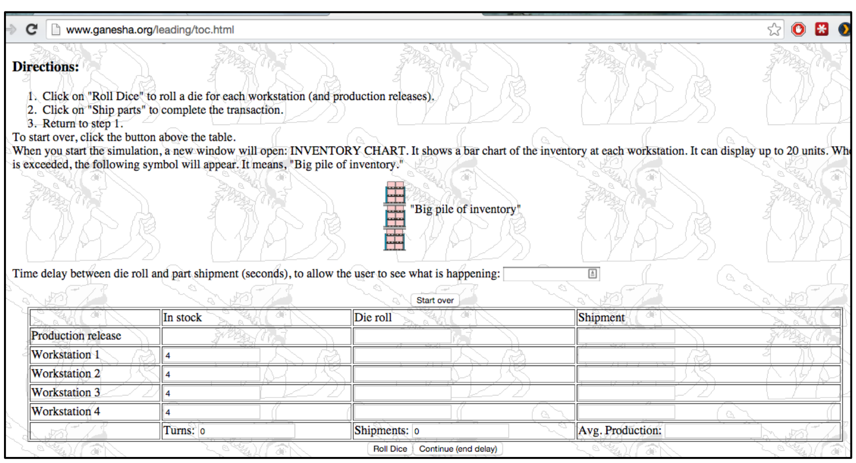

FIGURE 5: Screenshot of existing online dice game

iPad version:

This version of the dice game is available in the iTunes app store and will work only on iPhones at a cost of $2.99 per copy. There is no multiuser option available but since it can be played as a mobile application, it is very convenient. Compared to the other versions, it is more interactive with animations and graphics, making it more appealing and fun to play. FIGURE 6 shows the screenshot of this version.

FIGURE 6: Screenshot of iPad version of dice game

New prototype:

A new prototype for the dice game was developed by the department of Systems Engineering and Engineering Management at the University of North Carolina at Charlotte (Kottayil, 2014). This prototype has limited functionalities and does not support any multiuser options. The future version of this game will have more configurability and real-time discussion platforms. Graphical interfaces and interactivity has been employed with the aid of animations. The final version will have 24/7 availability in multiple platforms with the help of the internet and appropriate technology. FIGURE 7 shows the screenshot of this version.

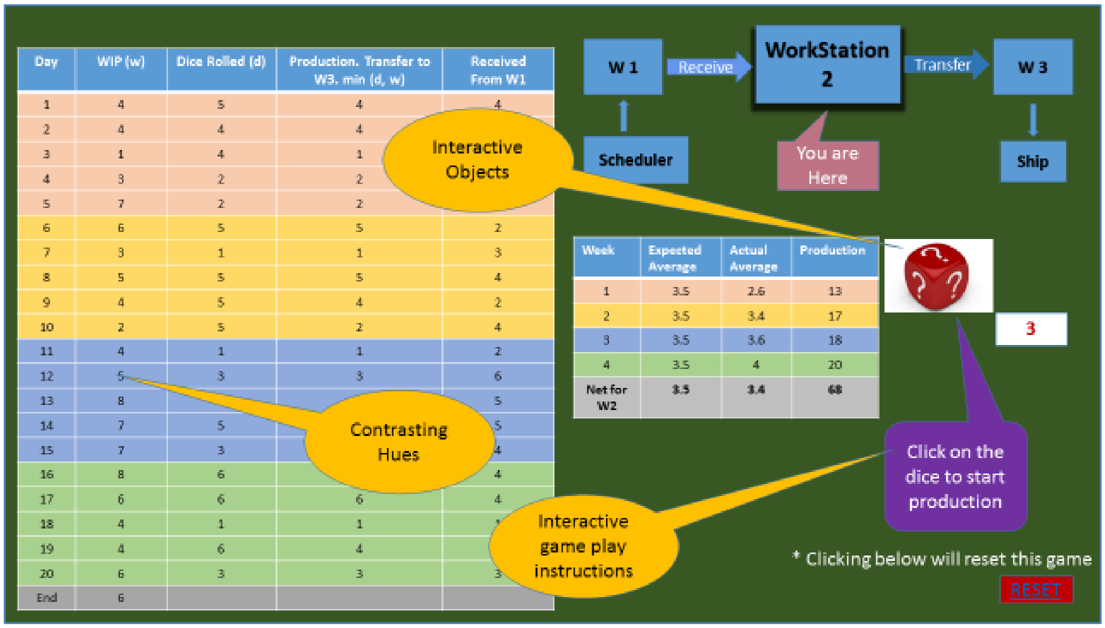

FIGURE 7: Screenshot of new prototype of dice game

2. Lampshade game:

The lampshade game was primarily developed to demonstrate the difference between the craft, mass and lean production systems. This in turn will help the participants to understand the advantages and disadvantages of these methods (Ozelkan & Galambosi, 2009).

Face-to-face classroom version:

The face-to-face classroom version of the lampshade game was developed by Ozelkan and Galambosi (2009). In the game, lampshades are produced from paper cups by performing operations like drawing, cutting, hole punching, coloring and inspection on the cup as shown in FIGURE 8. The order of the operations may vary depending upon the type of production system emphasized, for example, raw inspection for mass production is done at the end of but in lean, inspection is performed at the beginning of production.

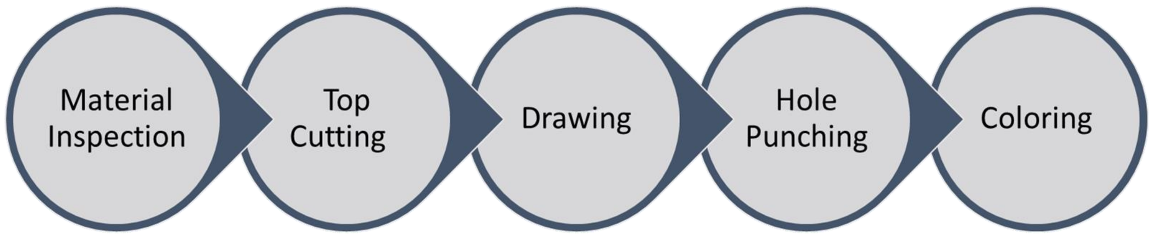

FIGURE 8: Illustration of the lean lampshade game

After playing in each production system, metrics such as cycle time, yield and profit are computed and compared to find out which system is better and under what conditions. Craft production is the mode of production where a single highly skilled operator performs all the required operations based on custom customer order. In mass production, there is a single skilled operator for each workstation producing standard products based on the market forecast. In lean production systems, multi-skilled operators produce standard products based on Just-In-Time manufacturing.

The supplier provides the raw materials, which in this case is the paper cup for the production. The next step is inspection in craft and lean but top cutting for mass production. In inspection, the products are visually inspected for damages or defects and moved on to the next step if they passe the inspection. Otherwise, they are returned back to the supplier. In the top cutting operation, the top part of the cup is cut off to resemble the shape of a lampshade. The operation is performed with the help of scissors. After the top is cut off, drawing is done on top of the cup as per the customer requirement with the help of a pencil. In certain lampshade designs, holes will be present on the cup to let the light pass through and hence give a better design to it. Therefore hole punching is done on the cup with the help of a puncher as per requirement. Finally, coloring is done on the cup on the drawings to get the final product. In craft and lean mode of production, this product will be directly shipped to the customer but in mass the product is kept for inspection now and only the products which meet specification and are not damaged are shipped to the customer. The rest are either categorized as scrap or moved to rework, if possible.

The face-to-face version of the game explains all three modes of production with appropriate exercises. During the craft mode, a single skilled operator performs all the functions from inspection to coloring as shown in FIGURE 9.

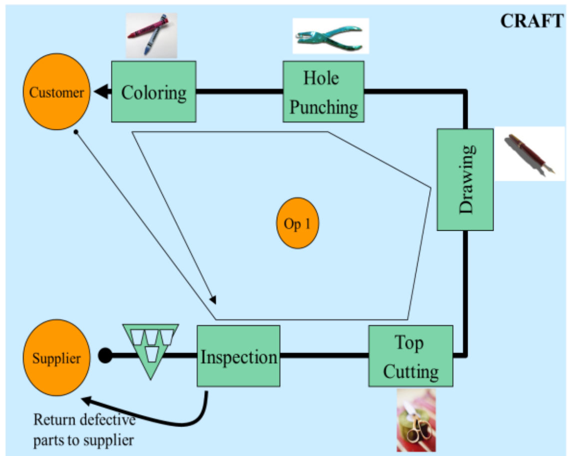

FIGURE 9: Illustration of craft production

In mass mode, an operator is needed for each workstation, so 5 students are asked to volunteer as the operators. Since the trigger for production in mass system is the market forecast, a dice was used to generate the forecast for production. A range of 1 to 6 will be used for production. Then the die is rolled again to forecast which product is to be produced. After the market demand has been forecasted, the production is initiated. Each operator performs his operation as shown in FIGURE 10, and keeps on producing till the forecasted value has been reached. After that the forecasting is done to produce the next batch of products. After all production is complete, it is verified to see if the demand is met.

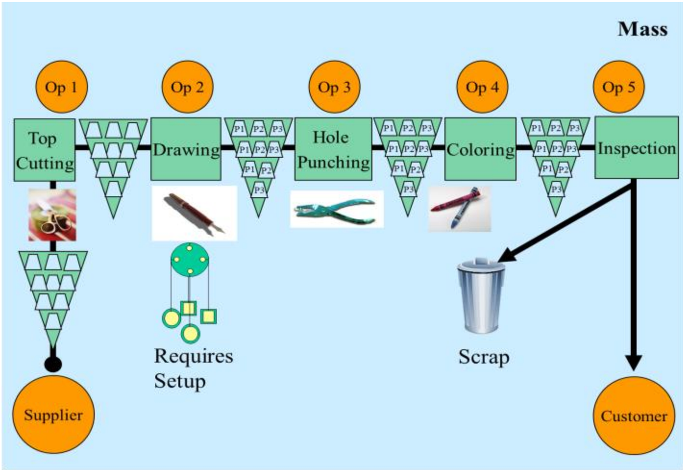

FIGURE 10: Illustration of mass production

In lean production, multi-skilled operators or participants are employed who handle more than one workstation, as depicted in FIGURE 11. The trigger for production is the customer order, which is called just-in-time manufacturing. A number of lean tools are used here making the production more efficient in comparison to other manufacturing modes:

- Visual Kanbans: Communicates what is needed. Similar to a To-Do note.
- Shadow Board: Organize tools and materials. Contains outlines of designated tools.
- Drawing Template: Reduces the die change time and hence the overall cycle time.
- Standard work**:** Documents the current best practice. Shown at the manufacturing floor.
- Alert Cards: To signal a breakdown or a bottleneck.

These tools are used by the operator for the purposes stated above. Finally, after all the modes of production are done, they are compared to analyze which mode is more efficient. Since all the modes of production are performed for equal time period, they can be compared.

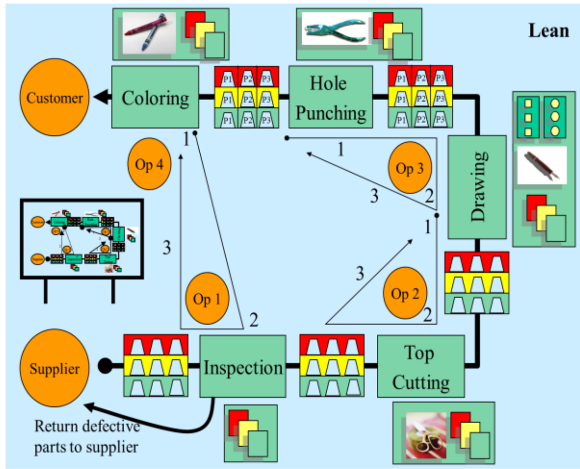

FIGURE 11: Illustration of lean production

CHAPTER 6: ANALYSIS OF CRITERIA OF SIMULATION GAMES

In this chapter, the second step of AHP, analyzing the criteria will be explained. It comprises of individual judgements and combined group judgements for the evaluating the preference of criteria.

The face-to-face classroom version of the dice game was deployed in the undergraduate class of SEGR 4090-M01: Lean Six Sigma System Design (Spring 2015) which is aimed to provide an understanding of the lean six sigma system design principles and tools. Hence this game was a proper platform for the testing of the game. Since the same group of users are testing all the different versions of the game, the within-subject design is emphasized, which yields more power and reduction in variance.

After the initial ranking of the design criteria, the user was asked to fill the pairwise comparison matrix of the design criteria as shown in TABLE 5 to capture the user's opinion on the significance of the different design criteria.

TABLE 5: User's preference on design criteria

	Dice Game	1	2	3	4	5	
	Criteria	Engagement Level	Substantive Learning	Complexity	Duration	Configurability	**Criteria Weights**
1	Engagement Level	1.00	0.54	1.90	3.44	3.16	27%
2	Substantive Learning	1.85	1.00	2.04	3.94	5.30	39%
3	Complexity	0.53	0.49	1.00	2.65	1.90	18%
4	Duration	0.29	0.25	0.38	1.00	0.47	7%
5	Configurability	0.32	0.19	0.53	2.14	1.00	10%
						Total	100%

The responses of 27 other undergraduate students from the same class were recorded and consolidated to obtain the response of the whole class. The undergraduate class of SEGR 2101-001: Systems Engineering Concepts (Fall 2015) with a 19 students played the online prototype of the lean lampshade game and also provided their feedback on the different design criteria. Their results were collected similarly and all the undergraduate responses were summarized in TABLE 6. From the TABLE, we can infer that the top 2 significant criteria are 'Engagement Level' followed by 'Substantial Learning'.

TABLE 6: Consolidated response on design criteria of undergraduates

Undergraduate	1	2	3	4	5	
Criteria	Engagement Level	Substantive Learning	Complexity	Duration	Configurability	Criteria Weights
Engagement Level	1.00	1.55	3.00	2.92	3.71	37.25%
Substantive Learning	0.64	1	2.41	2.62	3.41	28.75%
Complexity	0.33	0.41	1	1.27	1.77	13.45%
Duration	0.34	0.38	0.78	1	2.51	12.95%
Configurability	0.27	0.29	0.56	0.39	1	7.58%
					Total	100%

The graduate students of 'EMGT 6915-O80, EMGT 6915-O90, INES 8090-O90: Engineering Decision and Risk Analysis (Spring 2015) class had played the face-to-face version of the lampshade game, so the preferences from 47 graduate students were collected. The online prototype of the lampshade game was forwarded to the students of EMGT 6980-081: Industrial & Technology Management Seminars as an optional assignment. All their design criteria preference was collected and is summarized in TABLE 7. From the TABLE, we can infer that the top 2 significant criteria are 'Substantial

Learning' followed by 'Engagement Level'. By comparing these results of the graduate criteria preferences to the undergraduate results, it seems that both groups find the same two criteria most important but in different order: undergraduate students prefer engagement level then substantial learning but for graduate students the order is reversed.

TABLE 7: Consolidated response on design criteria of graduates

Graduates	1	2	3	4	5	
Criteria	Engagement Level	Substantive Learning	Complexit y	Duration	Configurability	**Criteria Weights**
Engagement Level	1.00	0.851	2.502	2.87	3.56	30.75%
Substantive Learning	1.17	1	3.19	3.43	4.47	37.31%
Complexity	0.39	0.31	1	1.69	2.04	14.04%
Duration	0.35	0.29	0.59	1	1.52	10.29%
Configurability	0.28	0.22	0.49	0.655	1	7.60%
					Total	100%

The purpose of assessing the design criteria is to understand the voice of the customer, in this case the voice of the students. The responses of both undergraduate and graduate students are combined together by taking the geometric mean (Aczél and Saaty, 1983). The previous work (Kottayil, 2014) had collected the user response of 9 graduate students which is also being incorporated to the combined preference. The combined preference for design criteria is shown in TABLE 8.

TABLE 8: Combined preference for design criteria

	1	2	3	4	5	
Criteria	Engagement Level	Substantive Learning	Complexity	Duration	Configurability	**Criteria Weights**
Engagement Level	1.00	1.15	2.74	2.90	3.63	34.02%
Substantive Learning	0.86	1.00	2.77	2.99	2.90	32.92%
Complexity	0.36	0.36	1.00	1.46	1.90	13.81
Duration	0.34	0.33	0.68	1.00	1.95	11.60%
Configurability	0.27	0.25	0.52	0.51	1.00	7.63%
					Total	100%

From TABLE 8, ‘Engagement Level’ and ‘Substantive Learning’ are most preferred by the students. . When designing a new game or prototype, these two criteria should be focused on, and the technical features that support these two criteria should be incorporated.

CHAPTER 7: STRUCTURE OF THE NEW ONLINE GAME SIMULATION

Based on the user feedback and evaluations of the different design criteria, a design framework for an online game simulation was designed. And using this design, an online prototype of the lampshade game was developed. After the initial testing of the classroom versions of the lampshade game, Quality Function Deployment (QFD) has been applied to capture the voice of the customer and to translate them into specific design requirements for the online lampshade game prototype. FIGURE 12 shows a simplified QFD. Customer Needs are the design criteria as described earlier. Critical-to-Quality (CTQ) measures are the design features of the online simulation game. Weights are the relative criteria weights obtained through the AHP Process. The numbers in the QFD table that are through 1 to 9 show the relationship of the customer needs to the CTQ measures, where a high number indicates a high relationship. For example the design requirement 'Gameplay' is extremely important for the customer need 'Engagement level', hence a score of 9 is entered at its intersection. Finally importance scores are computed for each CTQ measure as a weighted combination of the relationships as follows:

$$A_j = \sum_{i=1}^{I} W_i * R_{ij} \text{ , } j=1,\dots,J$$

where W_i is the importance or rank of the customer needs i=1, ...,I, and

R_{ij} is the score entered in the relationship matrix i=1, ...,I, and j=1,…,J

Customer Needs	CTQ Measures							
	Feedback	Animations	Pre & Post Test	Gameplay	Multimedia Guidance	Embedded Quiz	Multiplayer options	Weight
Engagement Level	9	7	3	9	7	5	7	34.02%
Substantive Learning	9	3	5	3	3	9	5	32.92%
Complexity	1	1	7	9	5	7	5	13.81%
Duration	3	5	1	9	5	3	7	11.6%
Configurability	3	7	1	7	3	1	7	7.63%
Relationships								
How Important	674	462	383	687	487	605	606	

FIGURE 12: Simplified QFD

Hence from the QFD, the A_j's are calculated and TABLE 9 lists the design requirements based on the score

TABLE 9: Rank of Design Requirements

Rank	Design Requirement	Score
1	Gameplay	687
2	Feedback	674
3	Multiplayer Options	606
4	Embedded Questions	605
5	Multimedia guidance	487
6	Animations	462
7	Pre and post test	383

Since a prototype was designed, some of these attributes were implemented in the prototype, while the rest these design requirements will be implemented in future versions. Those attributes which had a higher ranking or score, were emphasized to get a good design. In future versions of the game, this ranking will help the game developers to achieve higher customer (student) satisfaction.

Instructional Objectives:

Instructional objectives describe what the audience will be able to achieve after a given learning experience. The objective of the game is to educate the audience about the basic concepts of manufacturing and hence derive which is the best manufacturing method among craft, mass and lean mode of production. Matching the desired objectives with the game attributes, or selecting the appropriate game attributes to achieve these objectives are difficult tasks. Any game that is designed for instructional purposes should be heavily linked to instructional objectives (Hays, 2005). FIGURES 13 and 14 which are adopted from Hayes (2005), provide a graphical interpretation of instructional effectiveness as the degree of overlap between learning objectives and game attributes. Through this visualization, it is easy to conceptualize a framework designed to match instructional game attributes with desired leaning outcomes.

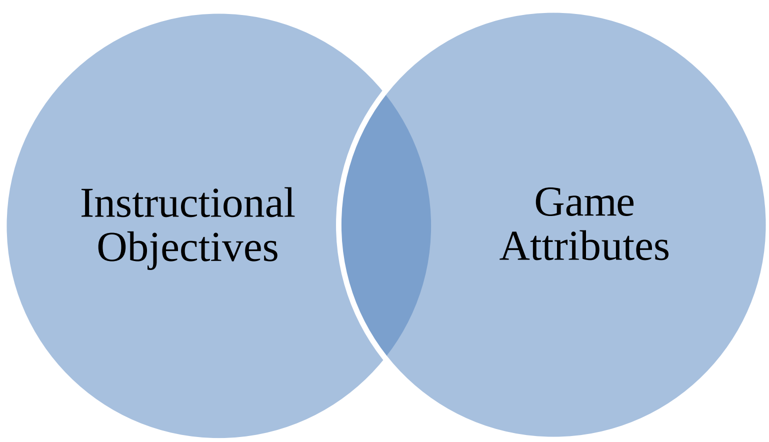

FIGURE 13: Low effectiveness of instruction

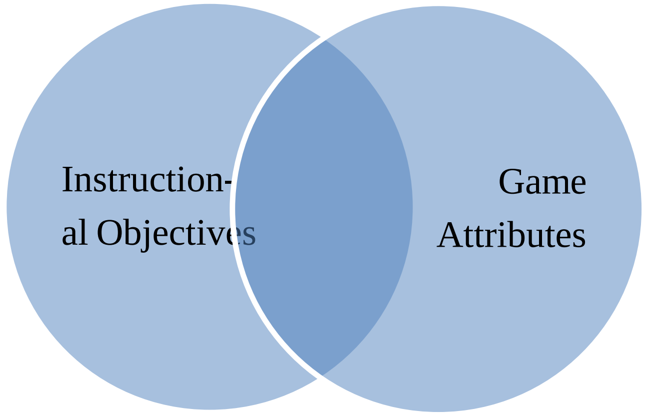

FIGURE 14: High effectiveness of instruction

The intersection in the Venn diagrams represents the effectiveness of instruction. In FIGURE 13, the area covered by the intersection of instructional objectives and game attributes is low, thus the magnitude of effective instruction is low. Whereas in FIGURE 14, where the interaction between them is high, the level of effective instruction is high. Based on the QFD analysis described earlier, the following technical attributes have been implemented into the game:

Gameplay:

Are all criteria equally important? It can be debated that they are all important but in practice that is not the case. When a person is asked to judge a simulation or a game, the first question they usually ask is “What is the game about?”. Here the focus is on the goals or objectives of the game, thus portraying more interest into the functional aspects in comparison to the aesthetic aspects. But more often, the focus of the user’s analysis is focused on the “What you can do” aspect, i.e. the gameplay of the game. In many scenarios, when the users get involved in a game, they neglect the context and even the goals in order to focus on the gameplay activities that should be carried out in order to complete the task or win it. Hence, when judging or designing a game, gameplay will be their first priority. Flaws in functional elements of a game cannot be balanced by any non-functional aspect of the design, since a very good context cannot sustain motivation if gameplay activities are ill-designed (Fabricatore, 1999).

A number of sources deal with gameplay, ranging from those that talk about gameplay extensively without defining it, to those who end up with the conclusion that gameplay is a synergy emerging from the interaction of certain elements included in the game, posing that it could be defined in a played independent manner, as “one or more casually linked series of challenges in a simulated environment” (Rolling and Adams, 2003). In between, there are those who hint at user-centered definitions, usually talking about what users are allowed to do in a game, and how the game is played (Bates, 2001; Lewinski, 1999; Rouse 2001). So even though there is no actual definition for gameplay, there exists the gamer’s version of gameplay which is

- What the user can do
- What other entities can do in response to user’s action (i.e. how the game responds to user’s decisions)

The two key features in gameplay are “interactivity” and “activity”. In order to be involved in an activity, the users have to interact with the elements present in the game. Interaction initiates a thought provoking process inside the user’s mind which will be analyzed and hence a default feedback will be given by the user. This in turn will improve the student’s understanding of the concepts. In an engaging environment, the users have queries and clear them by observing the results of their own interaction with the simulation and make sense of what they see. The students can be engaged or motivated by having them use the simulation in an appropriate context such as a homework or activity.

Any ludic activity involves the interaction with concrete or abstract objects (Bruner, 1972). These objects are commonly referred as toys (Crawford, 1984), and in order to use them the user requires a level of skill which should be achieved through the training process in the game itself. These objects are first introduced to the user in the beginning of the game (Bruner, 1972), which are used in the game only when the user feels that he has understood and grasped its properties (Hutt, 1966). The use of toys and their relationships are regulated by rules, which organize a set of activities and turns it into a complete and coherent game (Bruner and Sherwood, 1976). For example, in the 'Lampshade game for lean manufacturing', there are a number of objects that are being used for manufacturing like hole puncher, scissors, crayons, pencil, etc., which are basic daily objects. But in order to be proficient in it, the user needs to have some practice and a clear introduction with the objects. The full functionality of the objects were not provided in this version of the game, since this is a prototype with an objective to introduce the objects to the user.

Other than the functional importance of the game, there is a fun side of it, which makes it more interesting and interactive. It is characterized by semantics, which will portray the first impression of the game, making the user like or dislike it. Since the game is designed for a general population, the designer can only choose the mechanics whose semantics will be attractive to users and ensure that they are coherent with the context and goals of the game. Hence in this prototype as well, the equipment's and terminologies used are in accordance to the manufacturing domain.

Multimedia guidance:

The multimedia attribute is a very important aspect, yet presents unusual problems and opportunities for researchers. Its nature of innovation is one of the most significant factor of surprise. Interactive multimedia are believed to be working with people as "partners" in the learning process (Salomom, Perkins & Globerson, 1991) by acting as "cognitive tools" (Lajoie, 2000; Lajoie & Derry, 1993). Hence, research designs must be creative in understanding this partnership, especially since this aspect of design is always adapting.

Multimedia acts as a guide through the process or presentation, texts about a particular topic or various illustrations, which brings an entertainment factor into the simulation. This combination of entertainment and education is termed as Edutainment (Li-Mei, Xue-Feng & Liang-Chen, 2003). Through this advancement, endless possibilities for learning and instruction have opened up. Media convergence, which is the sharing and interaction of voice, data and video has also found its place in education, especially higher education. It has changed the curriculum of many universities around the world. Hence students are able to interact with the teacher and the subjects through multimedia teaching. As the teacher does not have to be in the class, the students can learn by themselves, which is the exact context of online learning.

In the lampshade game, audio guidance has been embedded in order to direct and explain each slide of the game. This will replace the need of a classroom teacher and act as a virtual teacher who will provide direction at all times. In this prototype, in order to provide a multimedia guidance to the game, the online website www.naturalreaders.com have been used for acquiring a female robotic voice. It is a free public website that provide the audio for the text we enter. Also video lectures by Dr. Ertunga Ozelkan have also been planted at strategic points in the game, which will explain the main concepts of the game and also summarize key points discussed. Each lecture video is about one to two minutes.

FIGURE 15 shows a screenshot of the lampshade game where a lecture video and the background video is present.

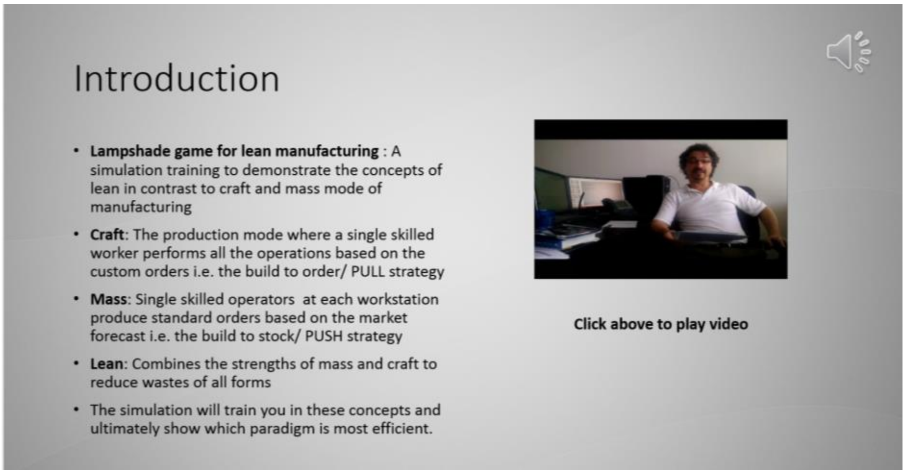

FIGURE 15: Embedded video lecture

Animations:

In a simulation, animations are noticed first. One of the major advantages of using a simulation is that it can be animated. Prior research has shown (Rouse III, R. (2001) that even though every kind of motion draws the attention of the user, if the animation is a simple motion without any proper meaning or application to the context, the user rarely develops new ideas or insights. In that scenario, the students are merely seeing the motion, but do not engage in understanding the meaning of the animation. But when the animation is triggered in response to user interaction or input, it portrays a cause and effect phenomenon, which forms new ideas, and the users begin to make connections. The user will have new questions in their mind, based on which they will analyze the simulations. They will investigate it in an attempt to make sense of the information it conveys. Hence the students engage themselves and create a connection with the simulation that usually occurs in real life problems or scenarios.

While animating, the objects that are allowed to be manipulated should be chosen and considered realistically. By constraining the options for animations and emphasizing certain controls, the simulation becomes more realistic and guides user thinking. It is also a useful approach to provide dummy objects that can be adjusted. If an object is adjustable, there comes a default thought that it will have an effect on the simulation. Hence if the user is only given access to those objects that have an impact, their misconception about which object/ parameter affects the game, can be cleared.

In the game developed, user interactive animations were embedded in order to provoke the thought process and for better engagement. For example, in the manufacturing process, when the product reaches a particular workstation like the drawing workstation, the user has to use the appropriate drawing equipment to perform the operation, which in this case is a drawing pencil. This conveys which operation to be performed at what stage and also how to do it. In the future versions, the user can be given the freedom to manipulate the tool as per his/her interest i.e. for the drawing operation the user can draw a design of his/her wish. Similarly, a number of animations have been embedded into the game that gives control to the equipment. FIGURE 16 depicts the production floor of mass production system where some of the equipment such as scissors, pencil and hole punchers have been animated to illustrate the functions of a typical production floor. For example, when a user clicks on the scissors, the object moves towards the foam cup upon which the action is performed and cuts the top part to give a shape resembling the lampshade.

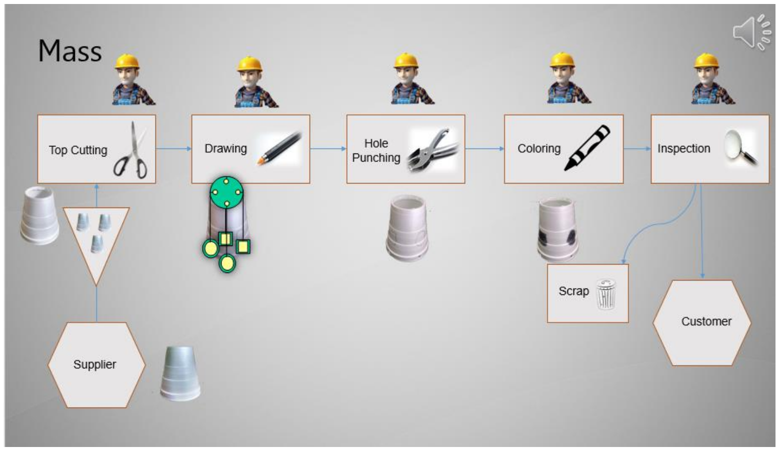

FIGURE 16: Animations in mass production

Feedback:

Feedback plays a major influence on learning and achievement, but its impact can be either positive or negative. It can briefly termed as a 'consequence' of performance. The power of feedback is influenced by the direction of the feedback relative to the performance on a task. Also, feedback is seen to be more effective when it is provided on correct rather than incorrect responses by the user, and this should be built as a chain forming from its previous links. Its impacts are maximum when the goals are specific and challenging but task complexity is low (Hattie & Timperley, 2007). The ripples on a pond as shown in FIGURE 17 depicts the main factors that stimulate the successful learning process. Among the results, the feedback was an essential factor in the learning process (Race, 2001). In most scenarios, feedback comes from external sources like fellow learners, tutors, and instructors, but feedback can also be provided as a response to the tasks performed by the user.

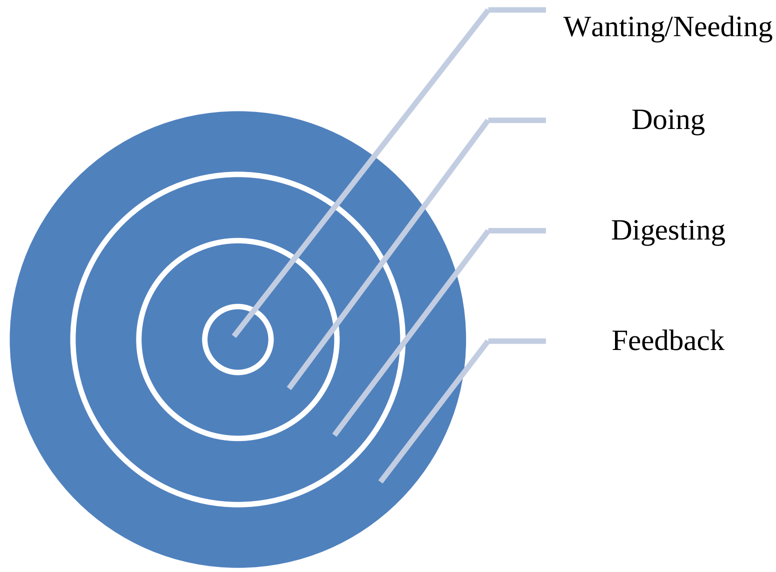

FIGURE 17: Ripples on a pond (Hattie & Timperley, 2007)

From the figure, imagine feedback being bounced back into the ripple of learning. It causes the ripple to keep on going, and increasing the intensity of the ripple, which deepens the leaning process. If there was no feedback, the ripple will fade and die out and hence the learning process will not be complete. Feedbacks can be provided during the event, after the event or both. In some scenarios, feedbacks can be provided in the absence of any learning action too and that may cause a learning event later. In the context of the 'ripples on a pond" phenomenon, strong ripples can bounce in bringing the whole system into life, and ideally cause learning-by-doing and also create motivation.

In context to the game, feedbacks are embedded into the game at specific points, which will either acknowledge the users action, or provide an information that occurred through the user action. As shown in FIGURE 18, a dialogue box pops up to inform the user that the required amount of products as desired by the customer has been produced. This feedback assures that the user is following the instructions correctly and moving in the right direction.

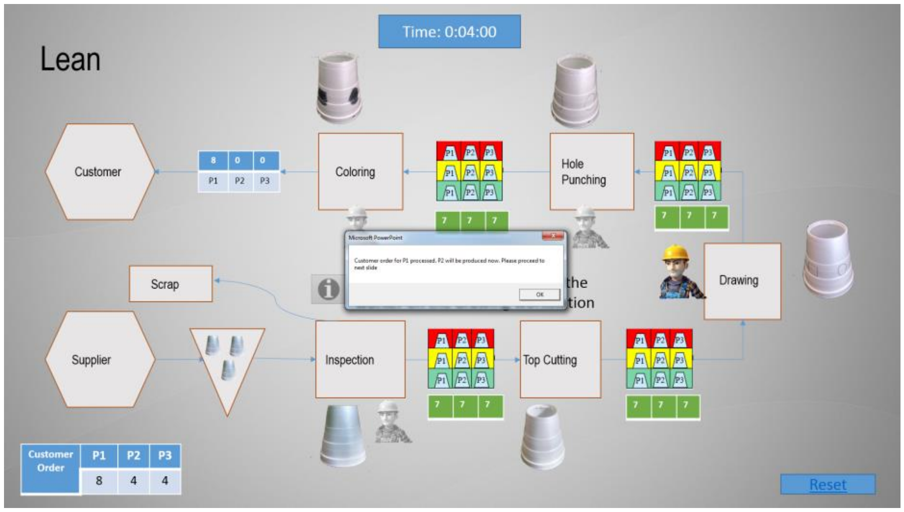

FIGURE 18: Feedback in lean lampshade game

Pre- and post-game quizzes:

Pre- and post-game assessments are a quick and easy way to assess the user's learning curve. These are quizzes or assessments administered at the "entry point" and "exit point" of the session. They can be standardized, locally-developed and tested for a broad general educational learning or within a specific discipline or course. It can also be performance-based. The pre-test is a series of questions related to the topic at hand, given to the users with an objective to determine their present knowledge level of the content. And after the completion of the course or training, the participants are given a post-test questionnaire. These questions can either be the same set of questions as the pre-test or a set of questions with comparable difficulty. The objective of the post-test is to check the whether the training was successful in increasing the participants knowledge of the training content. The pre-test also has a secondary objective to guide the users on which topics the training will be emphasizing and hence making them more perceptive towards that information. A well-designed pre and post-test can also help the trainer to understand which concepts were taught well and which ones need more concentration or time or even the need for an alternative method to cover it in the training session. The pre-test can also be considered as test of entry behavior, which will determine if the user has the necessary prerequisites for playing the game. FIGURE 19 depicts the pre- and post-assessment model charting the process of learning and deployment of the assessments.

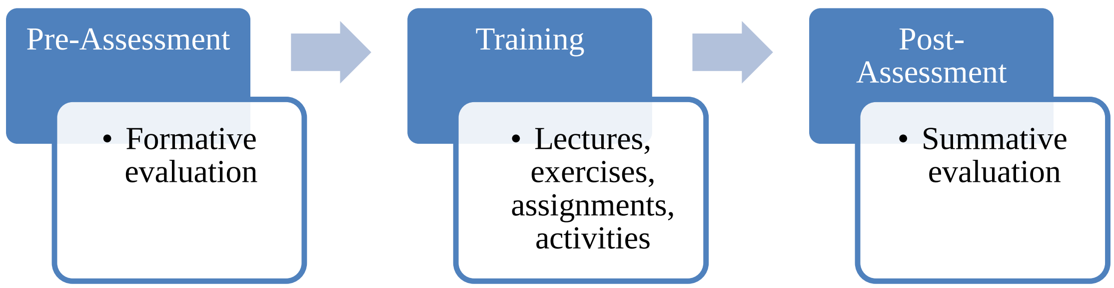

FIGURE 19: Pre-post assessment model

If the same batch of questions from the pre-test are used again in the post-test, those results can be compared to evaluate how much the user has learned through the training process.

In the face-to-face version of the lampshade game, 10 questions were asked in the pre-test, which were repeated in a randomized order for the post-test. Since the same questions are repeated, the change in the score will show if the training was instrumental in improving the user's knowledge about the concepts of manufacturing. These questions have been displayed in APPENDIX B.

In the online prototype of the lampshade game, an online testing website named 'Classmarker' was used, which enables to create a professional, easy to use online quiz that is automatically graded. After the pre- and post-tests were created using this website, the links to the quizzes were embedded into the prototype. When the user plays the simulation, these links will pop up at appropriate places prompting them to take these test. Since tests are automatically graded in real time, the users can see their change in score.

Embedded quizzes:

Quizzes can be used for multiple purposes: to motivate the user, to help the user remember or recollect, to assess what was learned, or to guide the user on what is being focused in the training. The pre-test for the lampshade game was used to motivate the user and the post-test was to assess what the user has learned. So these embedded quizzes are being used here not only to guide the user but also help the user remember or recollect information.

During the training, it may be a good idea to stop and review what has been explained till that point. By repeating the content in the form of quizzes, the learning process becomes stronger. The objective of these quizzes is not to assess the user but to find a method to review the content, so it is recommended that quizzes are not be graded. These quizzes can be designed in a number of ways. A sequencing quiz-type can be implemented where the user has to sequence or arrange a number of steps in the process. This is suitable for the lampshade game, since the manufacturing process is being explained, and the quiz can ask the user to arrange the options in the correct order. Another quiz that can be used in the lampshade game is the labelling quiz, where a picture is shown to the user and the user is asked to label it. For example, in the lampshade game, a number of tools like hole puncher, drawing templates, and visual cards are used, so these can be labeled by the user as part of a quiz.

In the prototype version of the lampshade game, a simple yes or no question was asked to the user to focus on one primary concepts and to capture the attention of the user, as shown in FIGURE 20. Another key point with quizzes during an online simulation is to keep it simple. Motivation should be maintained throughout the course so that the user will continue to learn and complete the training.

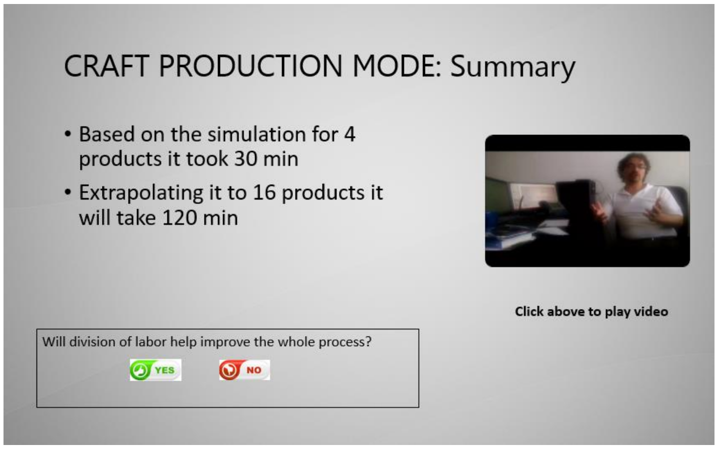

FIGURE 20: Embedded quiz in lean lampshade game

CHAPTER 9: ANALYSIS OF ALTERNATIVES FOR SIMULATION GAMES

This chapter explains the third step of AHP, the analysis of alternatives. The criteria for evaluation and the alternatives under study have already been explained in the previous chapters. In both the dice game and the lean lampshade game, there are multiple alternatives that are being compared by the user to understand which alternative or version is better with respect to the criteria being considered.

Dice Game:

For the dice game, there are 4 different versions of the game (alternatives), namely the face-to-face game, existing online game, the prototype developed by Kottayil (2014) and the iPhone version. TABLE 10 shows the comparison of the game by one user based on the criterion ‘Engagement Level’

TABLE 10: Pairwise comparison of alternatives based on engagement level

Evaluation of alternatives based on Engagement Level						
		1	2	3	4	
		Face-to-face	Existing Online	New Prototype	iPad App	**Alternative Scores**
1	Face-to-face	1	7	1/5	3	25.4%
2	Existing Online	1/7	1	1/3	1/5	5.5%
3	New Prototype	5	3	1	7	56.7%
4	iPad App	1/3	5	1/7	1	12.4%
					Total	100%

For determining the best alternative for individual judgments, the geometric mean or priority vector will be the metric for comparison. It is calculated following the same process as explained in step 3 for each pairwise comparison. The group judgement of all the judgements is computed and is shown in TABLE 11.

TABLE 11: Group judgement based on engagement level

Evaluation of alternatives based on Engagement		1	2	3	4	
		Face-to-face	Existing Online	New Prototype	iPad App	**Alternative Scores**
1	Face-to-face	1	3.67	2.27	3.25	48.2%
2	Existing Online	0.27	1	1.26	0.33	12.3%
3	New Prototype	0.43	0.79	1	0.33	12.3%
4	iPad App	0.31	3	3	1	27.2%
					Total	100%

Similarly the group judgement for all criteria are calculated. After group judgements for all criteria are computed, it is summarized in a 4x5 matrix (4 alternatives and 5 criteria). Similarly, the weights that were calculated are also summarized in a 5x1 column vector. The dot product of this priority vector and the criteria matrix will yield the final score for each alternative. The dataset for the pairwise comparisons of alternatives for individual judgments is provided in Appendix A. TABLE 12 shows the evaluation of all alternatives and TABLE 13 shows the computation of the final scores of alternatives.

TABLE 12: Group judgement for evaluation of alternatives (38 students)

Evaluation of alternatives based on Engagement		1	2	3	4	
		Face-to-face	Existing Online	New Prototype	iPad App	**Alternative Scores**
1	Face-to-face	1	3.67	2.27	3.25	48.2%
2	Existing Online	0.27	1	1.26	0.33	12.3%
3	New Prototype	0.43	0.79	1	0.33	12.3%
4	iPad App	0.31	3	3	1	27.2%
					Total	100%

Evaluation of alternatives based on substantive learning

		1 Face-to-face	2 Existing Online	3 New Prototype	4 iPad App	**Alternative Scores**
1	Face-to-face	1	4.75	2.41	2.45	48.5%
2	Existing Online	0.21	1	1.31	1.34	16.4%
3	New Prototype	0.41	0.75	1	2.12771346	19.1%
4	iPad App	0.40	0.74	0.46	1	12.9%
					Total	100%

Evaluation of alternatives based on complexity

		1 Face-to-face	2 Existing Online	3 New Prototype	4 iPad App	**Alternative Scores**
1	Face-to-face	1	2.73	2.96	2.12	42.9%
2	Existing Online	0.36	1	1.09	1.45	18.4%
3	New Prototype	0.33	0.91	1	2.43	19.6%
4	iPad App	0.47	0.68	0.41	1	12.7%
					Total	100%

Evaluation of alternatives based on duration

		1 Face-to-face	2 Existing Online	3 New Prototype	4 iPad App	**Alternative Scores**
1	Face-to-face	1	2.72	1.92	1.61	35.98%
2	Existing Online	0.36	1	1.16	1.18	17.80%
3	New Prototype	0.51	0.85	1	1.93	20.33%
4	iPad App	0.61	0.84	0.51	1	15.20%
					Total	100%

Evaluation of alternatives based on configurability

		1 Face-to-face	2 Existing Online	3 New Prototype	4 iPad App	**Alternative Scores**
1	Face-to-face	1	4.29	2.49	3.24	51.20%
2	Existing Online	0.23	1	1.76	1.95	19.97%
3	New Prototype	0.40	0.56	1	1.71	16.66%
4	iPad App	0.30	0.51	0.58	1	11.62%
					Total	100%

TABLE 13: Calculation of final scores for alternatives (38 students)

	Engagement Level	Substantive Learning	Complexity	Duration	Configurability
Face-to-face	0.4821	0.4859	0.5120	0.4295	0.3599
Existing Online	0.2721	0.1297	0.1162	0.1274	0.1521
New Prototype	0.1226	0.1647	0.1997	0.1845	0.1781
iPad App	0.1232	0.1909	0.1667	0.1963	0.2033

X

	Criteria Weights
Engagement Level	0.3725
Substantive Learning	0.2875
Complexity	0.1345
Duration	0.1295
Configurability	0.0758

	Final Score
Face-to-face	0.4711
Existing Online	0.1823
New Prototype	0.1573
iPad App	0.1640

The results of the pre- and post-test questionnaire of 38 students are consolidated and summarized in TABLE 14. The increase in score from 3.9 to 7.2 clearly shows the increase in the substantial learning of the students.

TABLE 14: Pre and post questionnaire scores

Pre	Post
3.9	7.2

Since the graduate students of EMGT 6915- Engineering Decision and Risk Analysis in Spring 2015 have already played the face-to-face classroom version of the lampshade game, the online prototype was forwarded to the same group and posted as a voluntary activity. This mode of testing is classified as the ‘within-subject’ design, since the same group is playing the different scenarios or versions.

As an example, the pairwise comparison of the two versions based on the design criteria 'Engagement Level' is shown in TABLE 15.

TABLE 15: Pairwise comparison of alternatives based on engagement level

Evaluation of alternatives based on **Engagement**					
		1	2	GM	Priority Vector
		Classroom Version	New Design		
1	Classroom Version	1	1/3	0.577	0.250
2	New Design	3	1	1.732	0.750
				2.309	

For determining the best alternative for individual judgments, the geometric mean or the priority vector will be the metric for comparison, as calculated before. Hence the group judgement of all the judgements are computed and the final score is shown in TABLE 16.

TABLE 16: Calculation of final scores for alternatives (15 students)

	Engagement Level	Substantive Learning	Complexity	Duration	Configurability
Face-to-face	0.7056	0.3768	0.4550	0.465	0.357
New Prototype	0.2944	0.5513	0.4566	0.447	0.582

X

	Criteria Weights
Engagement Level	0.3075
Substantive Learning	0.3730
Complexity	0.1404
Duration	0.1020
Configurability	0.0760

	Final Score
Face-to-face	0.5459
New Prototype	0.4501

Lampshade Game:

The lampshade game has been played by both undergraduate level and graduate level students. Here, a mix of 'within-subject' design as well as the 'between-subject' design was emphasized since in some tests the same students played all versions of the game (within-subjects) and in some scenarios different students played different versions of the game (between subjects).

The undergraduate class of SEGR 4090-M01: Lean Six Sigma System Design (Spring 2015) played the face-to-face classroom version of the lampshade game. This was the same class that played all four versions of the dice game, so their preference on the design criteria has already been collected. The users were asked to rate the game using a Likert scale of 1 to 9 based on the design criteria as shown in TABLE 17.

TABLE 17: Individual scores based on design criteria (example from one student)

No	Criteria	Score
1	Engagement Level	6
2	Substantive Learning	4
3	Complexity	3
4	Duration	3
5	Configurability	2

Similarly 26 other undergraduate students played the game and their consolidated results are shown in TABLE 18. Since they had already taken the pre- and post-test during the dice game, hence it was not taken during this session.

TABLE 18: Consolidated scores for face-to-face lampshade (27 students)

No	Criteria	Score
1	Engagement Level	5.59
2	Substantive Learning	5.22
3	Complexity	4.33
4	Duration	4.00
5	Configurability	4.26

After the online prototype of the lampshade game was developed, the undergraduate class of SEGR 2101-001: Systems Engineering Concepts of Fall 2015 played the version and provided their feedback. 19 students were asked to rank the online prototype of the lampshade game based on the design criteria using a Likert scale from 1 to 9. The consolidated response is shown in TABLE 19.

TABLE 19: Consolidated scores on online prototype of lampshade game (19 students)

No	**Criteria**	**Score**
1	Engagement Level	4.88
2	Substantive Learning	5.41
3	Complexity	4.03
4	Duration	4.76
5	Configurability	3.82

These students also took the pre and posttest questionnaires and the consolidated results are shown in TABLE 20. Here as well, a significant learning curve can be observed from a pre-test score of 5.37 to a post-test score of 7.58 (maximum possible score is 10).

TABLE 20: Pre-post scores by undergraduates for online prototype (19 students)

Pre	**Post**
5.37	7.58

From the graduate level, the batch of ‘EMGT 6915- Engineering Decision and Risk Analysis’ of Fall 2015 played the face-to-face classroom version of the lampshade game. Their scores are summarized in TABLE 21

TABLE 21: Graduates response on classroom lampshade game (38 students)

No	Criteria	Score
1	Engagement Level	5.92
2	Substantive Learning	5.87
3	Complexity	3.87
4	Duration	3.63
5	Configurability	4.05

These students took the pre- and post-test questionnaires and those results are summarized as the mean score of these students for pre- and post-test in TABLE 22. These results show a clear increase in understanding of the concepts discussed through the training.

TABLE 22: Pre-post results by graduates for classroom lampshade (38 students)

Pre	Post
3.8	7.2

After the online prototype of the lampshade game was developed it was forwarded to the graduate students of 'EMGT 6980-081: Industrial & Technology Management Seminars' of Fall 2015 as an optional assignment. Since they had not played the face-to-face classroom version, they were asked to rate the online version based on the design criteria in a scale of 1 to 9. Their results are summarized in TABLE 23.

TABLE 23: Graduates response on online prototype of lampshade (15 students)

No	Criteria	Score
1	Engagement Level	5.53
2	Substantive Learning	7.67
3	Complexity	4.67
4	Duration	5.47
5	Configurability	4.6

These users had also taken the pre- and post-test questionnaires, which is summarized in TABLE 24.

TABLE 24: Pre-post results by graduates for the online prototype (15 students)

Pre	Post
6	7.866667

CHAPTER 9: SELECTION OF BEST SIMULATION GAME ALTERNATIVE

This chapter explains the fourth step of AHP, selection of the best alternative. The best alternative is selected based on the final scores for different alternatives of the different games. Additionally, a statistical analysis is performed on the separately collected scoring data for each simulation sessions.

Dice Game:

TABLE 25 summarizes the final scores for different alternatives. Different colors are used in the table to categorize the alternatives. The highest scores for each criterion are marked in dark orange. Lighter color represents a decreased score. The table shows that the face-to-face version has performed the best by scoring highest in all design criteria. The next in rank is the new prototype. Despite the technical implementation limitations, the new prototype performed well. According to the undergraduate students, the prototype needs improvement in its duration. A statistical analysis (ANOVA) will be performed in the next chapter to investigate if there is a statistically significant difference between these scores for the different versions of the game.

TABLE 25: Final Score of Dice game (38 students)

Dice Game		Criteria & Weights					Final Score
		Engagement Level	Substantive Learning	Complexity	Duration	Configurability	
		0.3725	0.2875	0.1345	0.1295	0.0758	
Alternatives	Face-to-face	0.4821	0.4859	0.5120	0.4295	0.3599	0.4711
	New Prototype	0.2721	0.1909	0.1997	0.1845	0.2033	0.1923
	iPad App	0.1232	0.1297	0.1667	0.1963	0.1521	0.1573
	Existing Online	0.1226	0.1647	0.1162	0.1274	0.1781	0.1740

Lampshade Game:

The same procedure was repeated to find the best alternative for the lampshade game as shown in TABLE 26. The same color code system was followed earlier in TABLE 24. The face-to-face classroom version of the lampshade has a greater score than the new prototype. The new prototype is clearly lacking in the 'Engagement Level'. Again, a statistical ANOVA analysis will be show in the next chapter to see if there is a statistically significant difference between these scores.

TABLE 26: Final score of lampshade game (15 students)

Lampshade Game		Criteria & Weights					Final Score
		Engagement Level	Substantive Learning	Complexity	Duration	Configurability	
		0.3075	0.3730	0.1404	0.1020	0.0760	
Alternatives	Face-to-face	0.7056	0.3768	0.4550	0.465	0.357	0.5459
	New Prototype	0.2944	0.5513	0.4566	0.447	0.582	0.4501

CHAPTER 10: STATISTICAL ANALYSIS OF USER RESPONSE

A one-way ANOVA was conducted to test whether the difference between the mean final scores for the four version of the dice game is statistically significant. The null and alternate hypothesis for this test is listed below:

H_0 : The mean final score for every alternative is same.

H_a : At least one alternative's mean score is different.

Its results are displayed in TABLE 27. Since the P value is less than alpha (selected as 0.05), the null hypothesis can be rejected, and it can be concluded that there is a statistically significant difference between the mean final scores.

TABLE 27: Results of one way ANOVA (28 students)

```
Analysis of Variance

Source    DF  Adj SS  Adj MS  F-Value  P-Value
Factor     3    1268  422.66    40.42    0.000
Error    108    1129   10.46
Total    111    2397


Model Summary

      S    R-sq    R-sq(adj)  R-sq(pred)
3.23378  52.89%     51.58%      49.34%


Means

Factor              N    Mean  StDev       95% CI
Classroom Version  28  12.372  4.125  (11.161, 13.584)
Existing Online    28   5.326  2.699  ( 4.115,  6.538)
New Design         28   5.355  3.479  ( 4.144,  6.567)
Ipad               28   3.631  2.330  ( 2.420,  4.842)

Pooled StDev = 3.23378
```

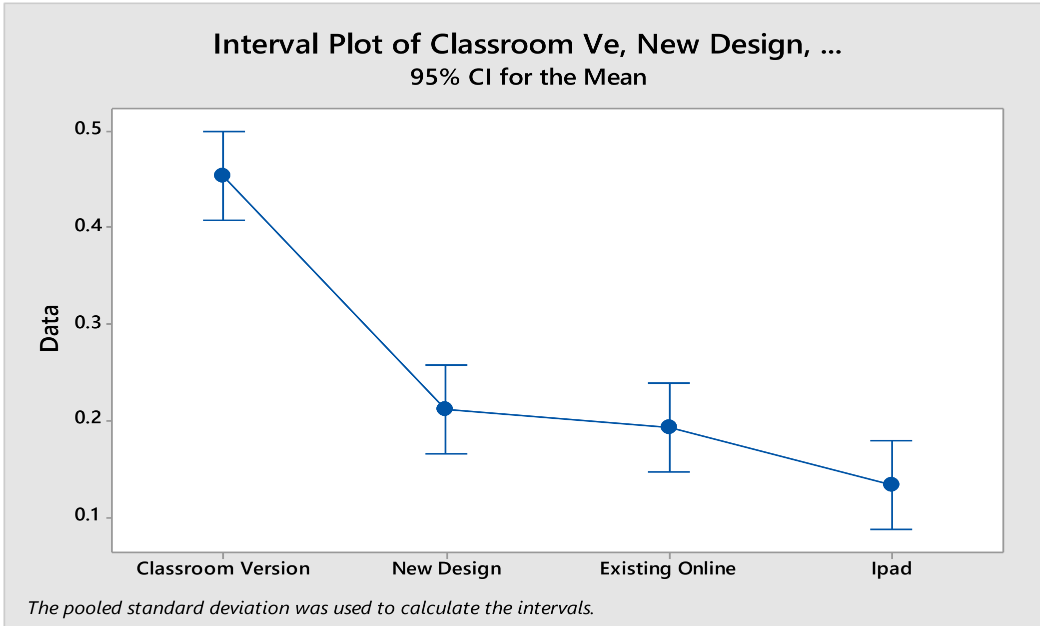

FIGURE 21: Interval plot (28 students)

FIGURE 21 shows the interval plot between the different versions. But in order to check which versions are significantly different from each other, a post-ANOVA analysis was performed using a Tukey test. The results of the Tukey test show that the mean score of the face-to-face classroom version is significantly higher than all other versions. It was also found out that we could not prove that there is a significant difference between the new design, existing online and iPad versions.

Based on the design criteria, a two-sample t-test was performed between the undergraduate class of 'SEGR 4090 M01: Lean Six Sigma System Design', Fall 2015 who played the face-to-face classroom version of the lampshade game and the undergraduate class of 'SEGR 2101-001: Systems Engineering Concepts', Fall 2015 who played the online prototype of the lampshade game. The hypotheses to be considered for each criteria are:

H_0: The mean final score for the face-to-face classroom version is the same as that of the online prototype version

H_a: The mean score of the face-to-face classroom version is not equal to that of the online prototype version

TABLE 28 shows the comparison of the design criteria 'Engagement level' between the face-to-face classroom versions to the online version. Since p-value is greater than alpha (0.05), the null hypothesis cannot be rejected. Hence the mean score of 'Engagement level' for the face-to-face classroom version is the same as that of the online prototype version. Also FIGURE 22 depicts the box plot between these two versions based on 'Engagement level'.

TABLE 28: Results of the two-sample t-test (27 face-to-face vs. 17 online)

```
Two-sample T for Engagement Level : Face-to face vs Engagement Level: Online


                           N  Mean  StDev  SE Mean
Engagement Level : Face-  27  5.59   2.31     0.44
Engagement Level: Online  17  4.88   2.00     0.48


Difference = μ (Engagement Level : Face-to face) - μ (Engagement Level: Online)
Estimate for difference:  0.710
95% CI for difference:  (-0.661, 2.081)
T-Test of difference = 0 (vs ≠): T-Value = 1.05  P-Value = 0.302  DF = 42
Both use Pooled StDev = 2.1946
```

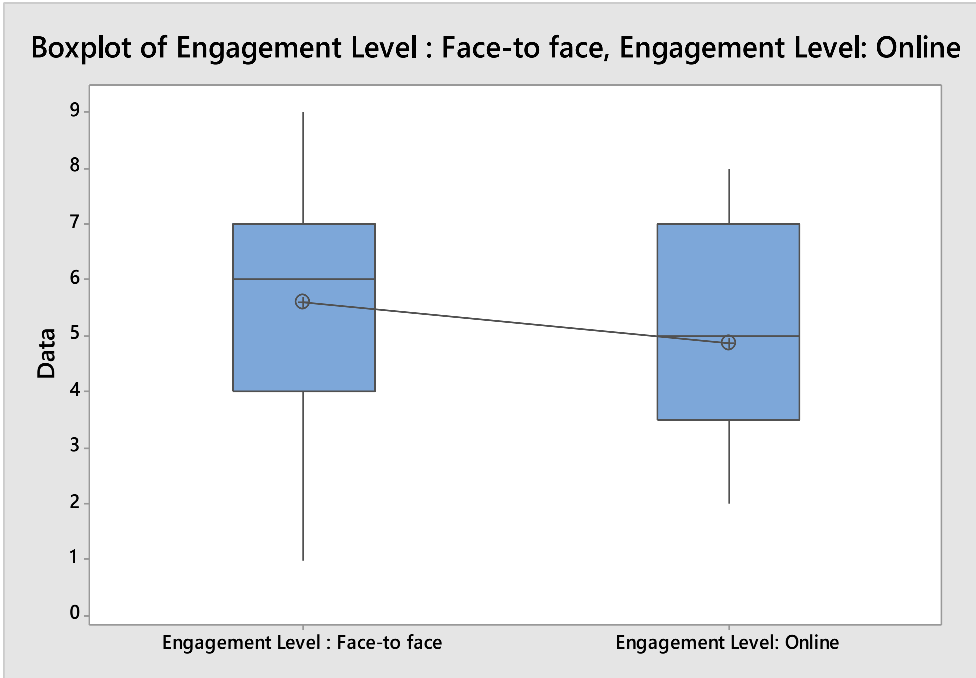

FIGURE 22: Boxplot based on engagement level (27 face-to-face vs. 17 online)

Similarly, the versions are statistically analyzed with the other design criteria as summarized in TABLE 29, and the boxplots of the corresponding comparisons are shown in FIGURE 23 to 26. Analyzing the results, for all criteria, except configurability, no significant difference between the design criteria for the two alternatives was found. It should also be noted that the criteria 'Duration' acquired a P-value of 0.069 which is very close to our selected alpha value, 0.005. Hence an absolute conclusion cannot be made in this scenario. A bigger sample size would give more insight, which can be done in future work.

TABLE 29: Results for Two-sample T test (27 face-to-face vs. 17 online)

Two-sample T for Substantive Learning: Face-to-f vs Substantive Learning: Online

	N	Mean	StDev	SE Mean
Substantive Learning: Fa	27	5.00	1.00	0.19
Substantive Learning: On	17	5.41	1.66	0.40

```
Difference = μ (Substantive Learning: Face-to-f) - μ (Substantive Learning:
Online)
Estimate for difference:  -0.412
95% CI for difference:  (-1.219, 0.396)
T-Test of difference = 0 (vs ≠): T-Value = -1.03  P-Value = 0.309  DF = 42
Both use Pooled StDev = 1.2921




Two-sample T for Complexity: Face-to-face vs Complexity: Online

                           N  Mean  StDev  SE Mean
Complexity: Face-to-face  27  3.96   1.37     0.26
Complexity: Online        17  4.03   1.26     0.30


Difference = μ (Complexity: Face-to-face) - μ (Complexity: Online)
Estimate for difference:  -0.066
95% CI for difference:  (-0.897, 0.764)
T-Test of difference = 0 (vs ≠): T-Value = -0.16  P-Value = 0.872  DF = 42
Both use Pooled StDev = 1.3291
Two-sample T for Duration: Face-to-face vs Duration: Online

                         N  Mean  StDev  SE Mean
Duration: Face-to-face  27  3.81   1.60     0.31
Duration: Online        17  4.76   1.71     0.42


Difference = μ (Duration: Face-to-face) - μ (Duration: Online)
Estimate for difference:  -0.957
95% CI for difference:  (-1.994, 0.080)
T-Test of difference = 0 (vs ≠): T-Value = -1.86  P-Value = 0.069  DF = 41
Both use Pooled StDev = 1.6461

Two-sample T for Configurability: Face-to-face vs Configurability: Online

                           N   Mean  StDev  SE Mean
Configurability: Face-to  27   4.70   1.06     0.22
Configurability: Online   17  3.385  0.870     0.24


Difference = μ (Configurability: Face-to-face) - μ (Configurability: Online)
Estimate for difference:  1.311
95% CI for difference:  (0.606, 2.016)
T-Test of difference = 0 (vs ≠): T-Value = 3.78  P-Value = 0.001  DF = 34
Both use Pooled StDev = 0.9992
```

TABLE 30 summarizes the conclusions of the statistical analysis. It can be inferred that except the criteria configurability, there is no significant difference between them with the given sample size (27 face-to-face vs. 17 online). For the criterion configurability, the face-to-face classroom version is preferred over the online version.

TABLE 30: Summary of two sample t-test (27 face-to-face vs. 17 online)

Criteria	p-value	Difference between face-to-face and online
Engagement level	0.302	No significant difference
Substantive learning	0.309	No significant difference
Complexity	0.872	No significant difference
Duration	0.069	No significant difference
Configurability	0.001	Significant difference, Face to face classroom version preferred

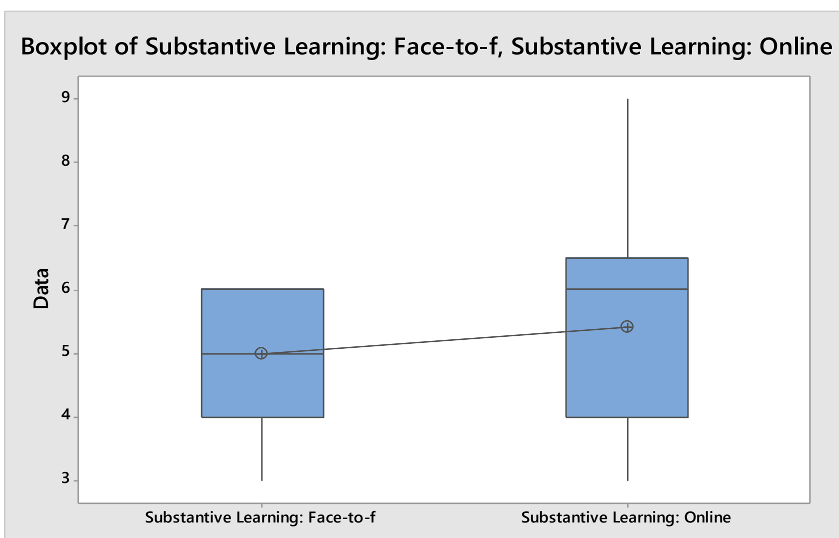

FIGURE 23: Boxplot based on substantive learning (27 face-to-face vs. 17 online)

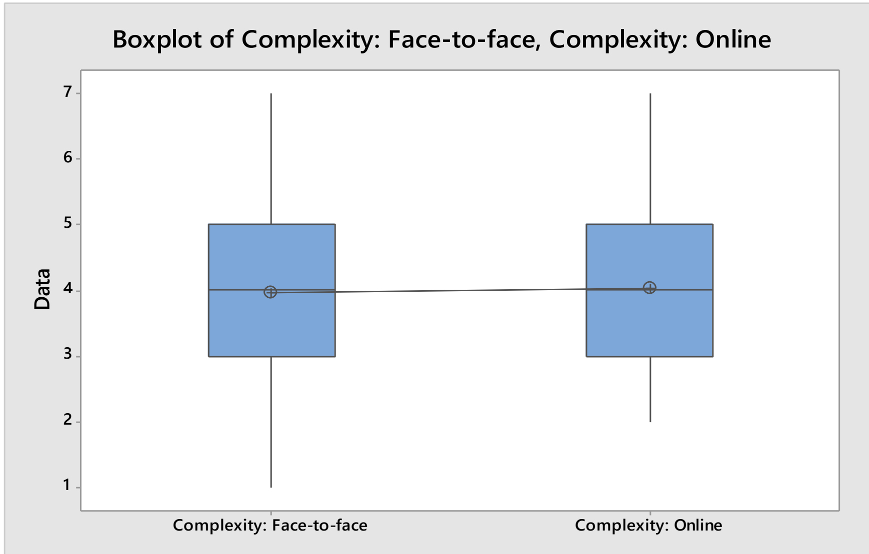

FIGURE 24: Boxplot based on complexity (27 face-to-face vs. 17 online)

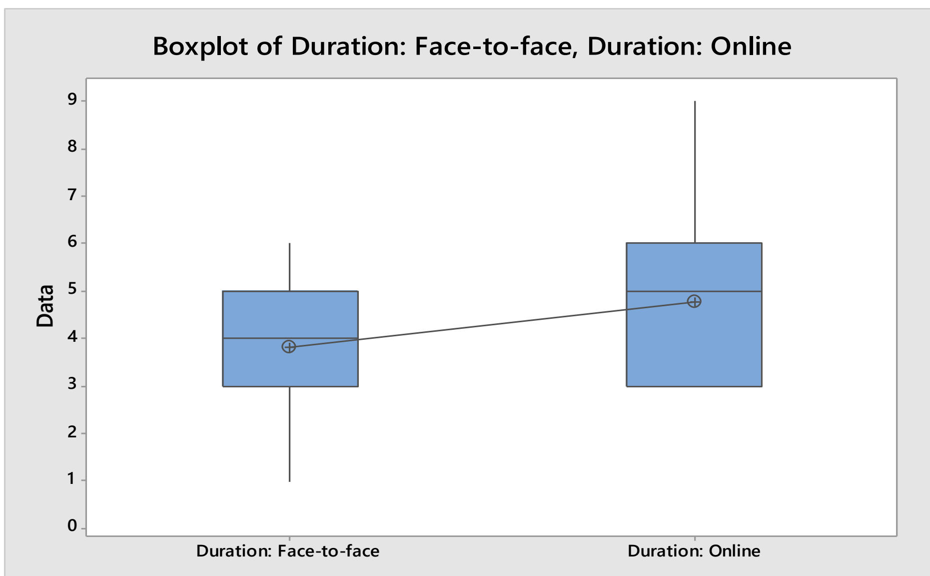

FIGURE 25: Boxplot based on duration (27 face-to-face vs. 17 online)

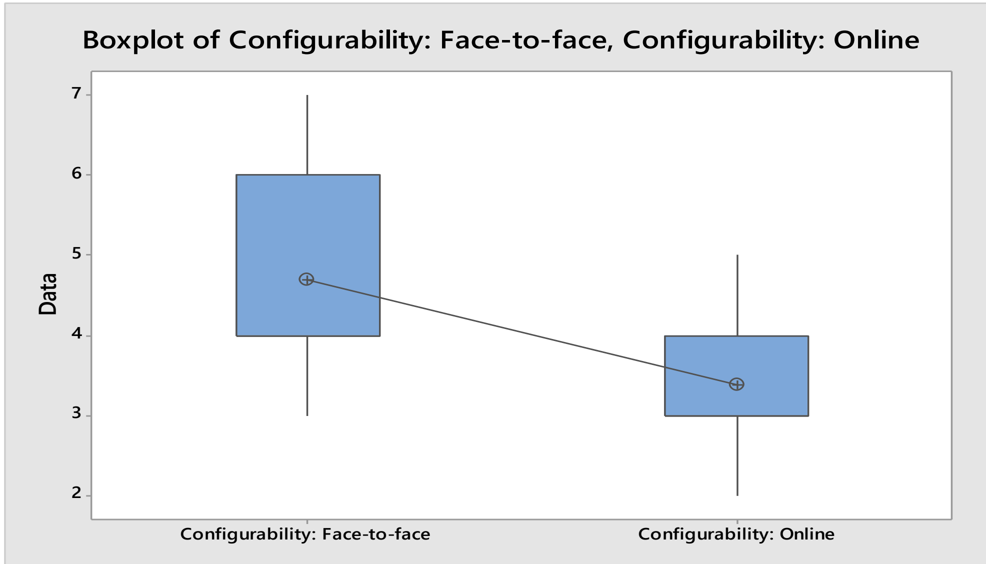

FIGURE 26: Boxplot based on configurability (27 face-to-face vs. 17 online)

Lampshade Game:

In order to statistically analyze the results of the lampshade game, a two sample T-test was performed based on the design criteria between the graduate class of 'EMGT 6915-Engineering Decision and Risk Analysis, Spring 2015' that played the face-to-face classroom version of the lampshade game and the graduate class of 'EMGT 6980-081: Industrial & Technology Management Seminars, Fall 2015' that played the online prototype of the lampshade game. The hypothesis for each criteria to be considered is:

H_0: The mean final score for the face-to-face classroom version is the same as that of the online prototype version

H_a: The mean score of the face-to-face classroom version is not equal to that of the online prototype version

TABLE 31 shows the comparison of the design criteria 'Engagement level' between the face-to-face classroom versions to the online version. Since p-value is greater than alpha (0.05), the null hypothesis cannot be rejected. So we conclude that based on the sample collected, no significant difference between the face-to-face classroom version and the online prototype of the lampshade game was found, based on the criteria 'Engagement level'. FIGURE 27 shows the boxplot for this test.

TABLE 31: Results Two-sample T test on engagement (38 face-to-face vs. 15 online)

```
Two-sample T for Engagement Level: Face-to-face vs Engagement Level: Online

                           N  Mean  StDev  SE Mean
Engagement Level: Face-t  38  5.92   2.07     0.34
Engagement Level: Online  15  5.53   1.81     0.47


Difference = μ (Engagement Level: Face-to-face) - μ (Engagement Level: Online)
Estimate for difference:  0.388
95% CI for difference:  (-0.838, 1.614)
T-Test of difference = 0 (vs ≠): T-Value = 0.63  P-Value = 0.528  DF = 51
Both use Pooled StDev = 2.0024
```

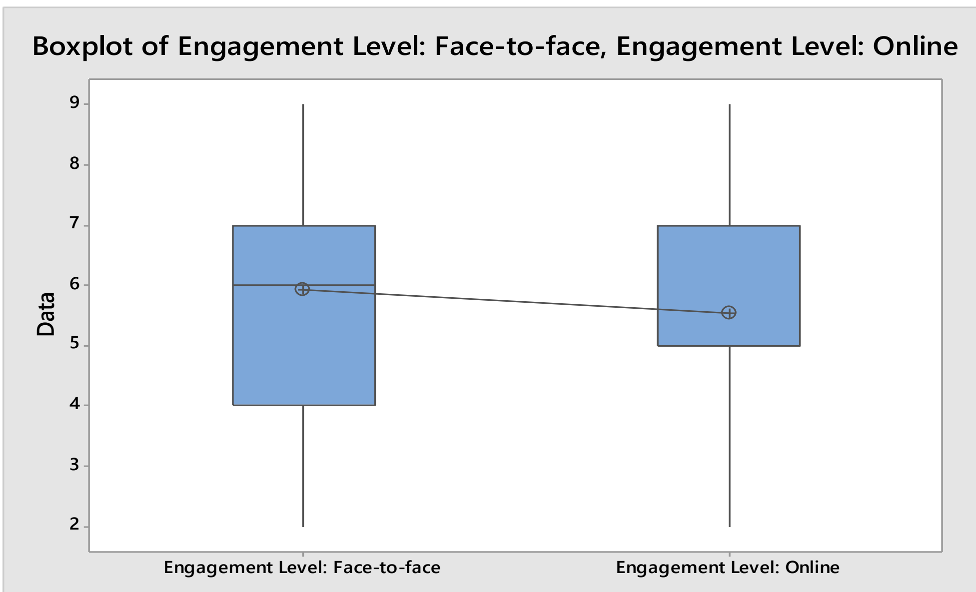

FIGURE 27: Box plot based on engagement level (38 face-to-face vs. 15 online)

Similarly the versions are statistically analyzed with the other design criteria as summarized in TABLE 32, and the box plots of the corresponding tests are shown in FIGURE 28 to 31. The p-value is greater than alpha (0.05) for the criteria complexity and configurability. Hence it can be stated that complexity and configurability were not proven to be significantly different. On the other hand, there seems to be a significant difference between substantive learning and duration for these two different versions of the game. They are more preferred in the online prototype in comparison to the face-face classroom version of the lampshade game.

TABLE 32: Results Two-sample T test (38 face-to-face vs. 15 online)

```
Two-sample T for Substantive Learning: Face-to-f vs Substantive Learning:
Online

                           N   Mean  StDev  SE Mean
Substantive Learning: Fa  38   5.87   2.24     0.36
Substantive Learning: On  15  7.667  0.816     0.21


Difference = μ (Substantive Learning: Face-to-f) - μ (Substantive Learning:
Online)
Estimate for difference:  -1.798
95% CI for difference:  (-2.997, -0.599)
T-Test of difference = 0 (vs ≠): T-Value = -3.01  P-Value = 0.004  DF = 51
Both use Pooled StDev = 1.9588



Two-sample T for Complexity: Face-to-face vs Complexity:Online

                           N  Mean  StDev  SE Mean
Complexity: Face-to-face  38  3.87   1.46     0.24
Complexity:Online         15  4.67   2.44     0.63


Difference = μ (Complexity: Face-to-face) - μ (Complexity:Online)
Estimate for difference:  -0.798
95% CI for difference:  (-1.888, 0.292)
T-Test of difference = 0 (vs ≠): T-Value = -1.47  P-Value = 0.148  DF = 51
Both use Pooled StDev = 1.7805

Two-sample T for Duration: Face-to-face vs Duration: Online

                         N  Mean  StDev  SE Mean
Duration: Face-to-face  37  3.49   1.66     0.27
Duration: Online        15  5.47   2.13     0.55


Difference = μ (Duration: Face-to-face) - μ (Duration: Online)
Estimate for difference:  -1.980
95% CI for difference:  (-3.090, -0.870)
T-Test of difference = 0 (vs ≠): T-Value = -3.58  P-Value = 0.001  DF = 50
Both use Pooled StDev = 1.8054



Two-sample T for Configurability: Face-to-face vs Configurability: Online

                           N  Mean  StDev  SE Mean
Configurability: Face-to  38  4.05   1.61     0.26
Configurability: Online   15  4.60   2.61     0.67
```

```
Difference = μ (Configurability: Face-to-face) - μ (Configurability: Online)
Estimate for difference:  -0.547
95% CI for difference:  (-1.734, 0.639)
T-Test of difference = 0 (vs ≠): T-Value = -0.93  P-Value = 0.359  DF = 51
Both use Pooled StDev = 1.9377
```

TABLE 33 summarizes the results of two sample t-tests. From the analysis, online version is preferred over the face-to-face classroom version for the criteria 'Substantive learning' and 'Duration'. For the other criteria, there is no significant difference between them, with the given sample size (38 face-to-face vs. 15 online).

TABLE 33: Summary of two sample t-test (38 face-to-face vs. 15 online)

Criteria	**p-value**	**Difference between face-to-face and online**
Engagement level	0.528	No significant difference
Substantive learning	0.004	Significant difference, Online version preferred
Complexity	0.148	No significant difference
Duration	0.001	Significant difference, Online version preferred
Configurability	0.539	No significant difference

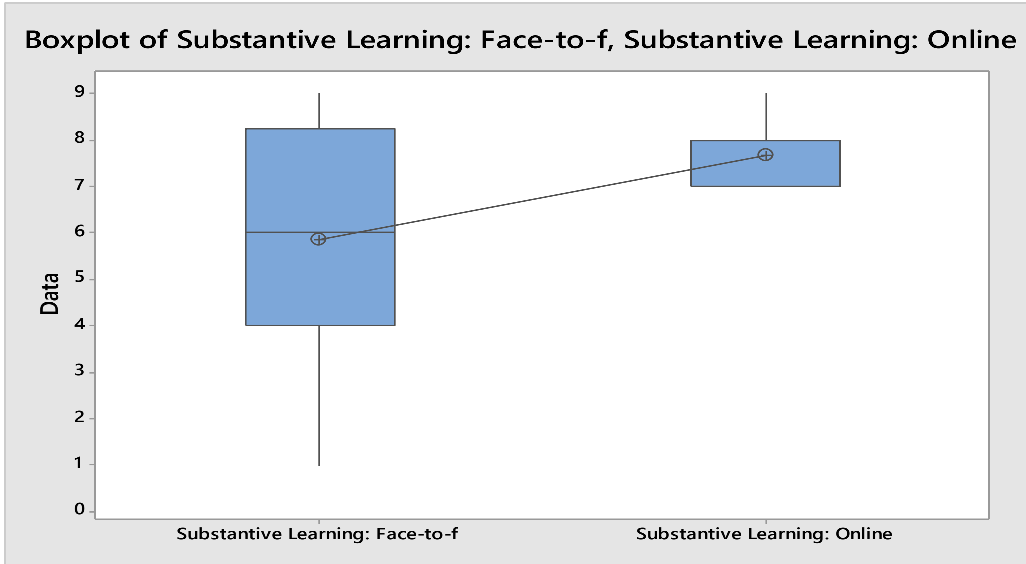

FIGURE 28 : Boxplot based on substantive learning (38 face-to-face vs. 15 online)

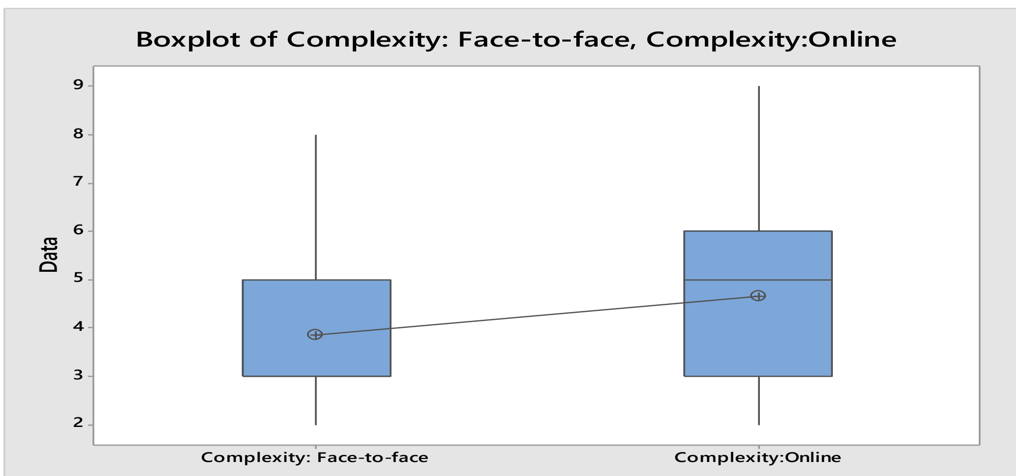

FIGURE 29: Boxplot based on complexity (38 face-to-face vs. 15 online)

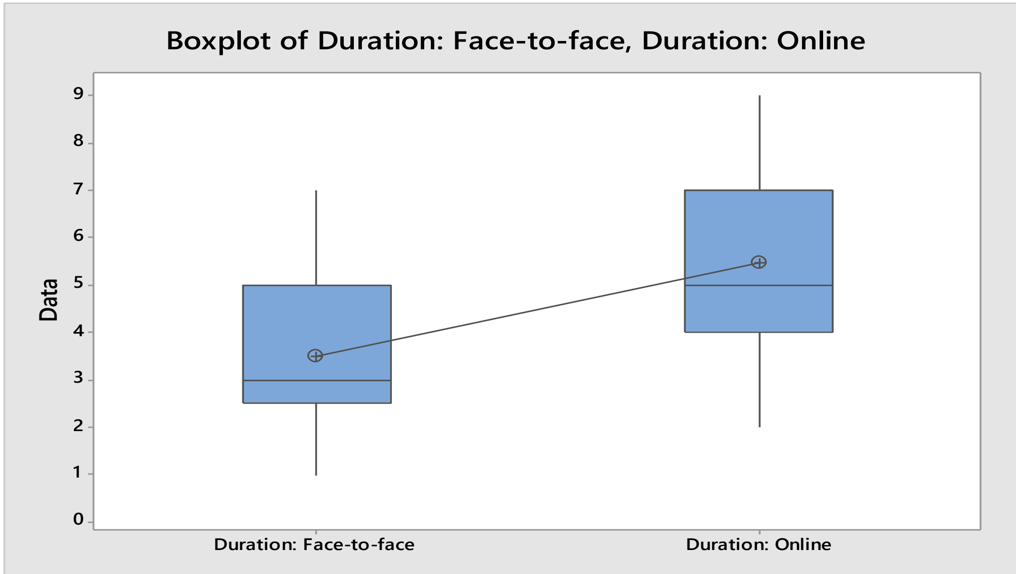

FIGURE 30 : Boxplot based on duration (38 face-to-face vs. 15 online)

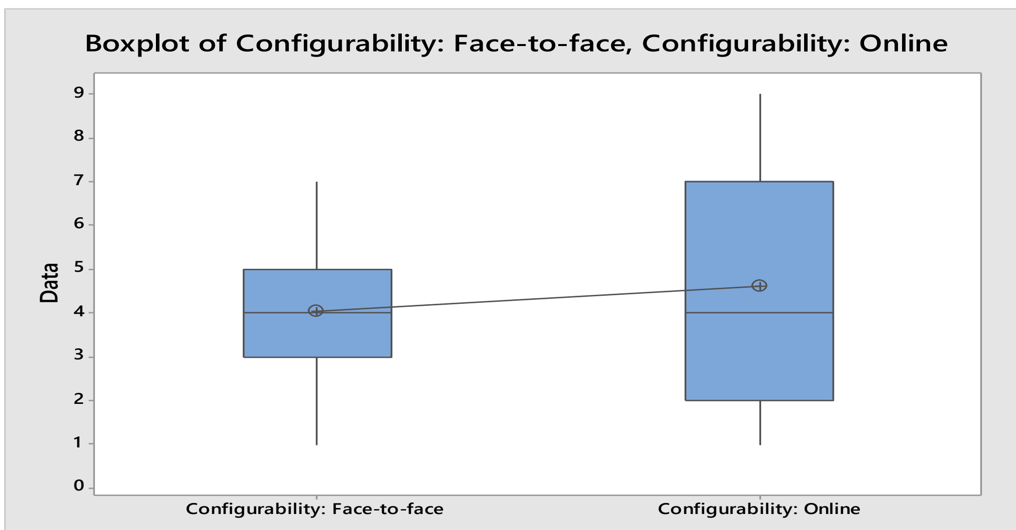

FIGURE 31: Boxplot based on configurability (38 face-to-face vs. 15 online)

Hypothesis Testing for Effectiveness of New Prototype:

Since 15 graduate students played the face-to-face classroom version and the new prototype of the lampshade game, a hypothesis test can be conducted to see if there is any significant difference for the new prototype compared to the face-to-face classroom version based on the design criteria. For this hypothesis test, the null and alternate hypothesis will be

H_0: The mean final score for the new prototype is the same as that of the face-to-face classroom version

H_a: The mean score of the new prototype is not same as that of the face-to-face classroom version.

Mathematically, H_0: $\mu 1 = \mu 2$ and H_a: $\mu 1 \neq \mu 2$, where $\mu 1$ and $\mu 2$ are the population mean scores for simulations based on new prototype and the face-to-face classroom version. To test the hypothesis, a paired t-test is performed. Output from Minitab statistical software is given in TABLE 34. The data input for this statistical analysis is provided in Appendix B. Since the p-Value is greater than alpha (0.05), the null hypothesis cannot be rejected. So we conclude that the mean final score for the new prototype is not significantly different from the face-to-face classroom version. The boxplot of differences in final scores is shown in FIGURE 32.

TABLE 34: Results of paired t-test (15 students)

```
Paired T for Classroom Version - New Design

                   N   Mean  StDev  SE Mean
Classroom Version  15  5.681  1.937    0.584
New Design         15  6.382  2.440    0.736
Difference         15  -0.70   4.25     1.28


95% lower bound for mean difference: -3.03
T-Test of mean difference = 0 (vs ≠ 0): T-Value = -0.55  P-Value = 0.702
```

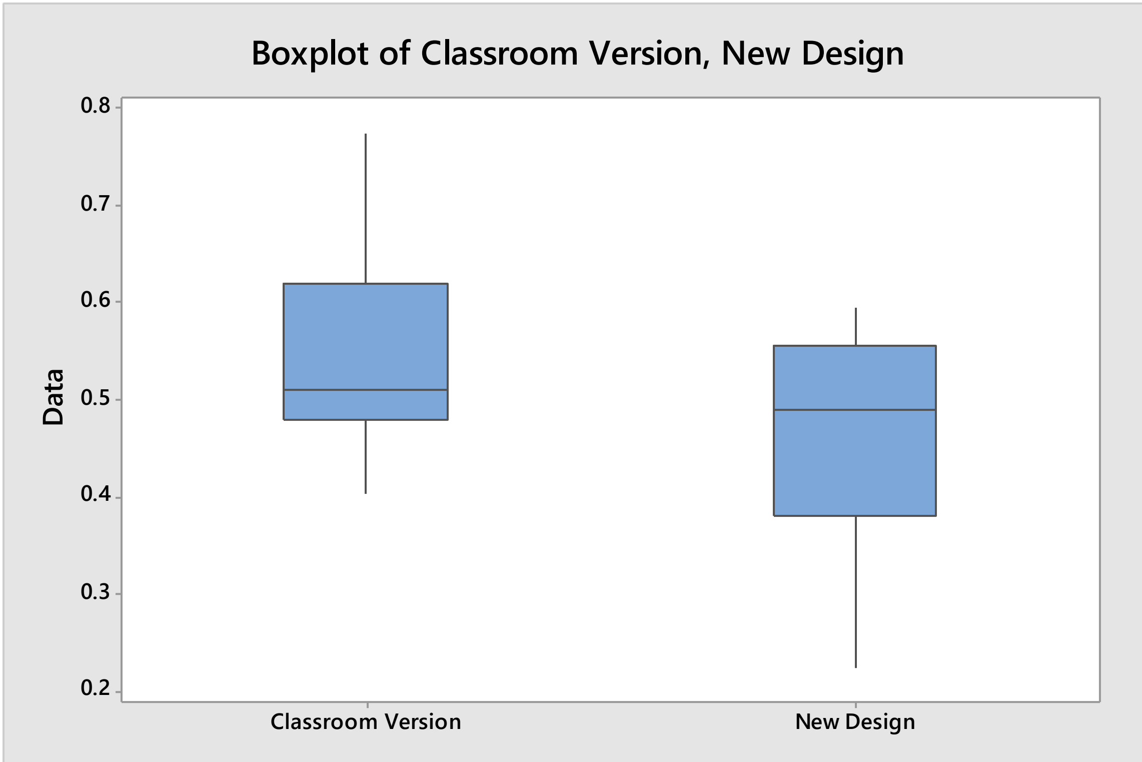

FIGURE 32: Box plot between classroom and new design (15 students)

CHAPTER 11: SUMMARY, RESULTS, AND CONCLUSIONS

Criteria Preference:

FIGURE 33 summarizes and compares the design criteria preference for 57 undergraduate and 47 graduate students. ‘Engagement level’ and ‘Substantial learning’ were the top two preferred criteria with little difference between them. It can be inferred from the graph that ‘Engagement level’ is the most preferred criterion for undergraduate student while ‘Substantial Learning’ is the most preferred criteria for the graduate students. This shows that for the undergraduate students they want the simulation game to be more engaging, while for graduate students they have a preference for simulations which provides more information and hence provides substantial learning. Taking a look at the other criteria, the graduate students prefer the simulation to emphasize more on ‘Complexity’ and ‘Configurability’, while the undergraduate students feel the ‘Duration’ of the game should be more important.

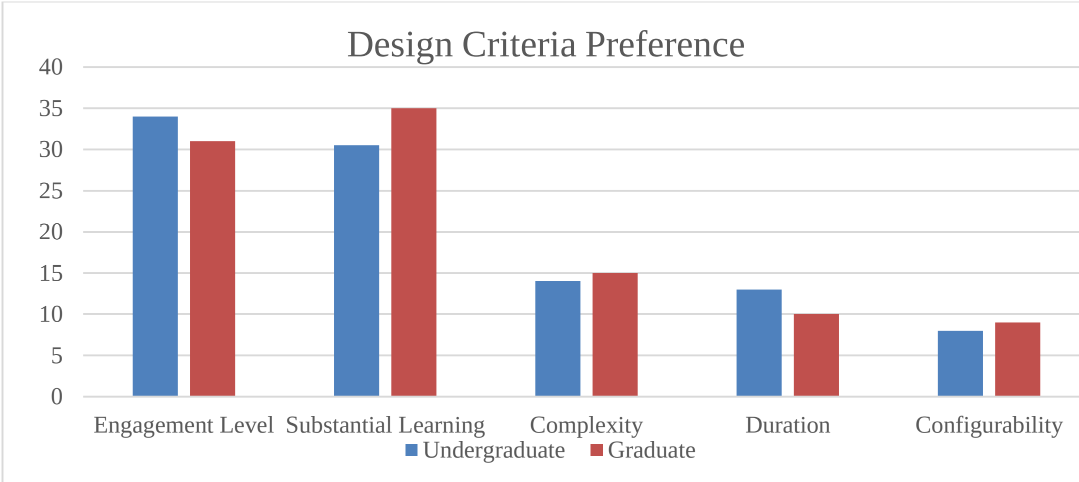

FIGURE 33: Design criteria preference

Dice Game:

FIGURE 34 shows the distribution of the user preference over the 4 alternatives of the dice game by 38 undergraduate students and 9 graduate students. The results for the graduate student have been retrieved from previous research (Kottayil, 2014). Using these data and the results derived from the statistical analysis, it can be stated that both the graduate and undergraduate level students prefer the face-to-face classroom version first. For all other versions it was found that there is no significant difference between the alternatives or versions at the alpha =0.05 level. The new design is just a prototype with some of the functional and aesthetic features in comparison to the existing fully functional online version. Even so, the new design has done well in comparison to the other versions, supporting the methodology followed for its design.

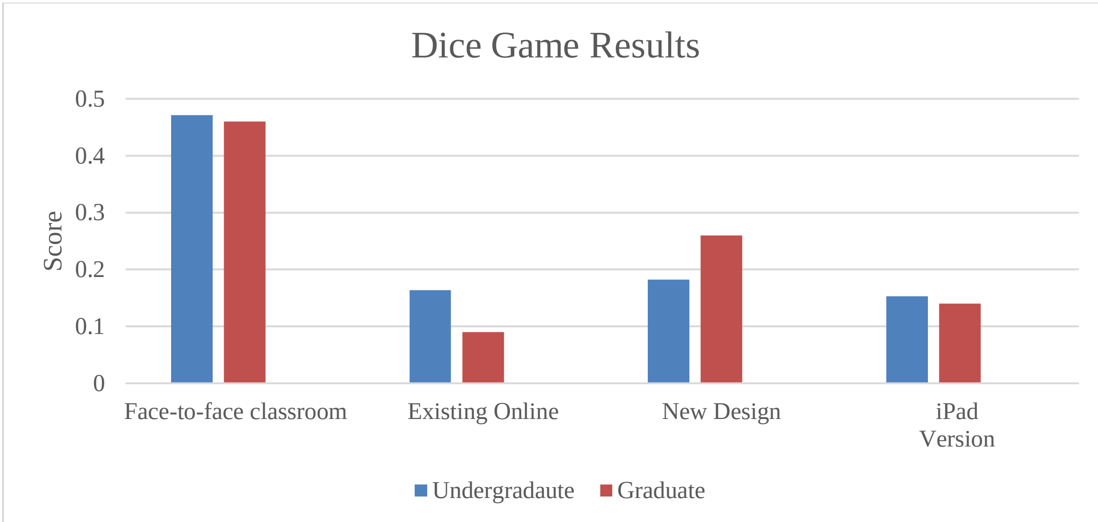

FIGURE 34: Dice game alternatives results

Lampshade Game:

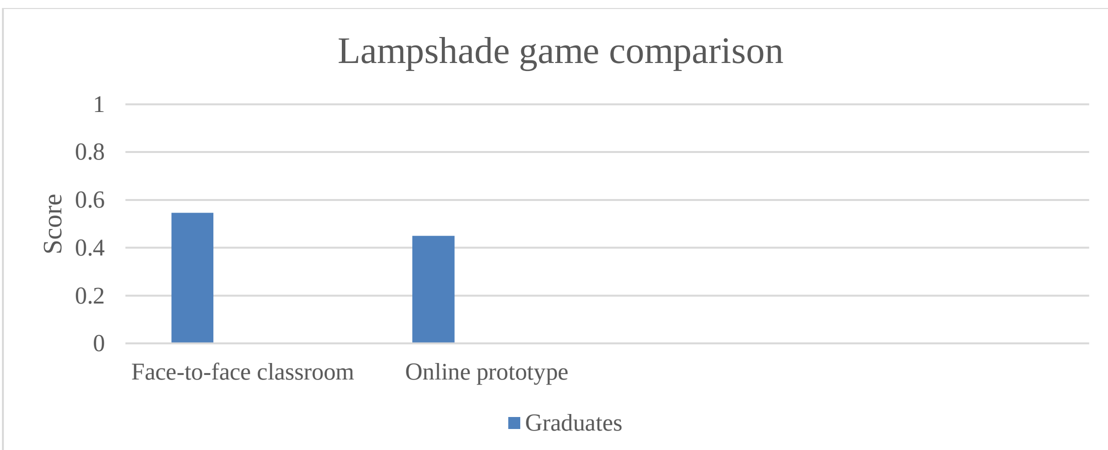

FIGURE 35: Lampshade game comparison for graduates

FIGURE 35 shows the two version comparison (face-to-face classroom and online prototype) for the lampshade game from a total of 15 graduate students. From the chart and the statistical analysis done it can be stated with a confidence of 95% that there is no significant difference between the face-to-face classroom version and the online prototype. Hence the online prototype has scored well in comparison to the existing face-to-face classroom version.

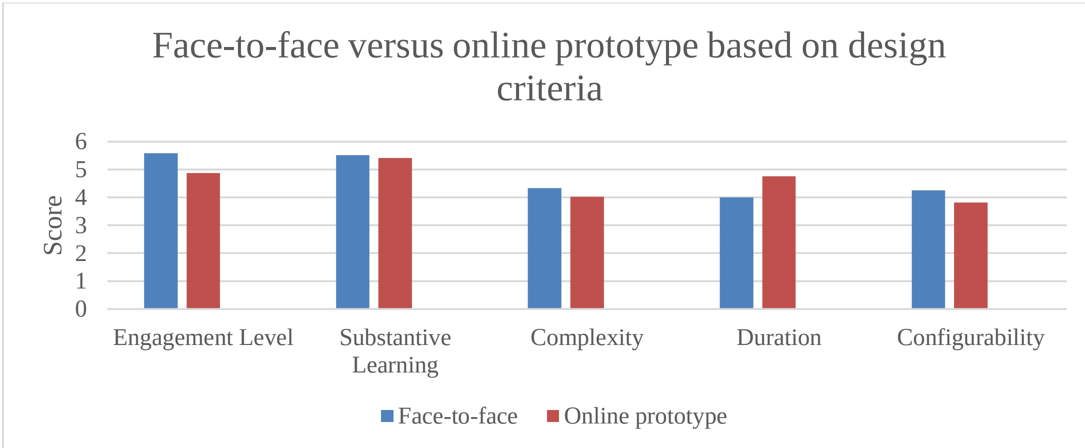

FIGURE 36: Face-to-face versus online prototype for undergraduates

Following the 'between-subject' design, a sample of undergraduate students had played the face-to-face version (27 students) and another sample had played the online prototype of the lampshade game (19 students). Those results are compared in FIGURE 36. From the figure and the statistical analysis done, we conclude that with the exception of two criteria, 'Configurability' and 'Duration', we could not have proven that there is a significant difference between the criteria. The criterion 'Configurability' is preferred more in the face-to-face classroom version, while a conclusion could not be made for the criterion 'Duration', since its p-value (0.069) is very close to alpha (0.05).

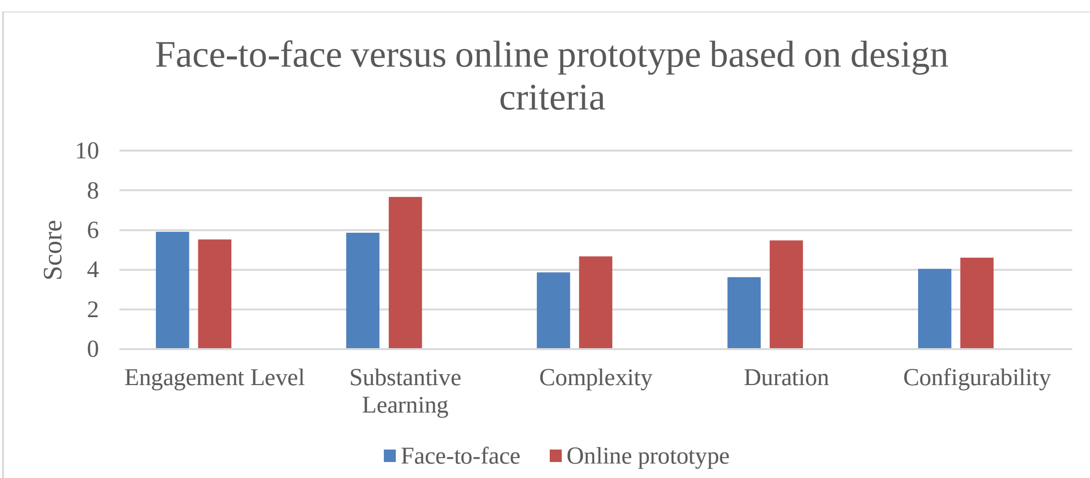

FIGURE 37: Face-to-face versus online prototype for graduates

Similarly among the graduate students, 38 played the face-to-face version whereas the online version was played by 15 students. Their scores were summarized and plotted in FIGURE 37. From the graph and the statistical analysis done, it can be stated with a 95% confidence that, except for the two criteria 'Substantive Learning' and 'Duration', we could not have proven that there is a significant difference between the criteria. For the criteria 'Substantive Learning' and 'Duration', the online version is preferred over the face-to-face classroom version.

Pre- and post-test:

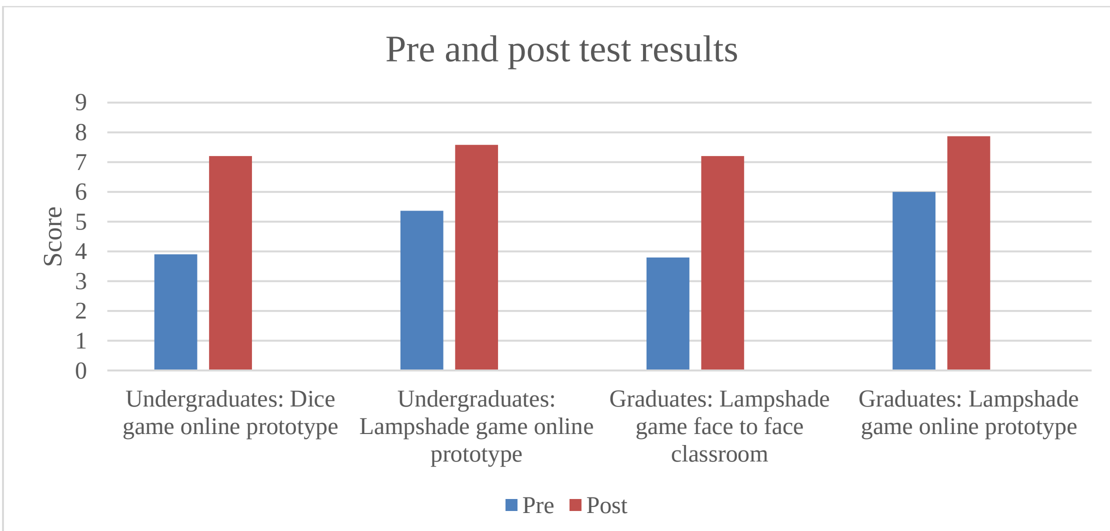

FIGURE 38: Pre- and post-test results

Each sample audience was asked to take the pre- and post-test to analyze the learning curve due to the training simulation or game. A total of 104 students took this test, out of which 57 were undergraduate students and 47 were graduate. Their results are summarized in FIGURE 38. In all scenarios, there was a significant learning, which implies that the training provided by these games have increased the knowledge in that particular area. The maximum post-test score was obtained after playing the online prototype of the lampshade game by the graduate students.

Lampshade prototype feedback:

The users who had the opportunity the play the online prototype of the lampshade game were also asked to give their feedback to improve the game. Some of the main points of their feedback to be used for improvement are as follows:

"I felt than some of the videos were not needed or too long. If this is to be used as part of an online class, I think it might be good to separate the lecture videos from the actual game"

- "It was a really good simulation of the actual process. But there was no interaction with other students. If it is possible to play this game in teams all working on it"
- "Improve some of the clip art [make it more modern]"
- "The monotonous robotic voice in the audio recordings was sleep-inducing"
- "A better experience using better tools can make the concept much easier to follow."
- "More of the Lean tools and methodologies could have been explained"
- "Computer generated audio can be replaced with real human audio"

Conclusions:

- Design Criteria:
    - ➢ 'Engagement Level' & 'Substantive Learning' are most preferred
        - ❖ 'Engagement level' is most preferred by the undergraduate students
        - ❖ 'Substantive learning' is most preferred by the graduate students
- Dice Game

  - Both undergraduate and graduate students prefer the 'face-to-face' version. It could not be proven at the selected 0.05 level of significance that there is a significant difference from the face-to-face version of the dice game.

- Lampshade Game
  - While the face-to-face version was preferred slightly more overall, it could not be proven at the selected 0.05 level of significance that there is a significant difference between the face-to-face classroom version and the new online prototype.
  - From the feedback, we can conclude that the new online prototype of the lampshade game needs to improve in the criterion 'Engagement Level'.

CHAPTER 12: RECOMMENDATIONS AND FUTURE RESEARCH

As mentioned in the conclusion section of the previous chapter, the new online prototype of the lampshade game developed as a part of this study is lacking in the criterion 'Engagement level'. Hence considering this criterion as a fundamental objective, the following design enablers can be emphasized as the means objective:

Direct transfer vs open-ended learning:

In educational designs, there exists two types of learning approaches: direct transfer (i.e. the traditional method) vs. open-ended learning (i.e. the alternative approach). In direct transfer approach, the developer uses predefined, concrete and easily measurable learning objectives. It is assumed that the learner consumes this information which has been implemented in the learning objectives. Books, lectures and other traditional methods emphasize this mode of learning. Game designers have also adopted this method, with specific objectives that are embedded into the game, in a hope that the user picks it up. But the developers do not have control on how the user interprets these messages, since different users have different perspectives and experiences. Furthermore, the message or information being discussed does not to be factual; it can relate to procedures, conceptual ideas or metacognition as well (Anderson & Lawton, 2009; Salas -et al., 2009).

In contrast to direct transfer, open-ended learning approach is not specially designed for learning certain objectives; it is more concerned with getting insight into a certain topic, by discussing it with people. But it does not mean that open-ended learning techniques do not have any predefined learning goals; it's just more broadly defined and abstract. Here the actual learning occurs after the training when the users are debriefed to let them reflect their experience. Since the users usually have trouble reflecting their learning experience while playing, the actual learning occurs here (Egenfeldt-Nielsen, 2005).Either the game is too complex or the user is too involved in the game to learn it. Debriefing can also be used in the direct transfer approach, but they more structured more like a post-test, to test whether the message came across rather than to elaborate their experience. For this prototype of the lampshade game, the direct transfer has been adopted. If the open-ended learning approach can be implemented, it will stimulate more engagement and substantive learning.

Challenge:

It has been discovered through prior research that individuals desire activities which involves challenges in an optimum level i.e. neither too easy nor too difficult (Malone & Lepper, 1987). These challenges can be obtained in a number of ways. The goals or objectives of the training should be clearly defined, but the possibility of attaining it should be uncertain. Difficulty levels, multiple goals, and an adequate amount of informational ambiguity can also be employed to keep the outcome uncertain. To keep track of the user's progress, performance feedback and scores can be kept. And most importantly the goals or objectives set should be meaningful to the user. In order to make the goals meaningful the activities should be linked to value personal competencies, the engaging competitive or cooperative motivations etc. can be employed.

Mystery:

As described by Malone and Lepper (1987), curiosity is the one primary vehicles which drives learning. Following Berlyne (1960), they described 2 types of curiosity as: sensory curiosity, which is the interest grown by novel sensations and cognitive curiosity which is the desire for knowledge. It is a human tendency to make sense of the world and it is driven by a curiosity about things that are unexpected or that cannot be explained (Loewenstein, 1994). Here also the right level of mystery should be installed. If a piece of information is only somewhat discrepant, it may be easily dismissed without paying much attention. If t the level of discrepancy is too high between our existing knowledge and the new information, it may be too confusing to understand. Hence the curiosity is stimulated by the optimum level of information gap: it should be neither too simple nor too complex. It should also be understood that curiosity and mystery are different. Curiosity is an internal attribute that exists inside the user, whereas mystery is an external feature of the game or training. Hence curiosity can be evoked by mystery.

Control:

By control, it refers to the exercise of authority or ability to regulate, direct or command something. Prior research comparing the effects of instructional programs that control all elements of the instruction (program control) to which the learner has control (learner control), has given mixed results (Hannafin & Sullivan, 1996). However, it was seen that user reactions and motivations consistently positively favor learner control. Cardova & Lepper (1996) found that motivation and learning was increased when students were given control over instructionally irrelevant parts of a learning activity, which would avoid the risk of students making a pedagogically poor choice. Also Morrsion et al. (1992)

found out that more positive attitudes were reported when students were allowed to choose the amount and the context of practice problems. Games and simulations provide a sense of personal control where users are given the freedom to select strategies, manage the direction of activity, and make decisions that directly affect outcomes, even if actions are not instructionally relevant. In this prototype, partial control has been given to the user in some aspects of the game. But due to limitations in the platform being used, most of the aspects are in program control. Hence in future versions, the model has to be designed for a user-controlled environment.

Additional future work:

Based on the test result and the feedback provided by the users, the following can be considered for future work:

- Lampshade game: Online prototype
    - Increase engagement level by providing more interaction. This can be achieved by deploying the additional design enablers like 'Open-ended learning', 'Challenge, and 'Mystery'.
    - Replace the robotic voice with a human voice to give the game a more personalized touch.
- Using a stronger platform for developing the game like Construct2 (Language: JavaScript) or Unity (Language C#). Further testing of the full version of the dice game and lampshade game along with iterative improvements to the design
- Possible updates to framework based on feedback from larger sample size
- Include the teacher's opinion into the analysis as they are also a major stakeholder in the teaching process.

- While developing the QFD, an expert's opinion can be used to enter values into the cells, since they are experts in developing games. This can be performed with multiple faculty members (teachers) and experts to further improve the results.

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APPENDIX A: RESPONSE DATA FOR AHP EVALUATION AND SCORING

Individual Response Data for AHP Evaluation of Criteria

The individual responses for criteria evaluation are listed below.

		1	2	3	4	5	**Criteria Weights**
		Engagement	Substantive	Complexity	Duration	Configurability	
1	Engagement Level	1	1/3	9	3	5	30%
2	Substantive Learnin	3	1	9	5	3	46%
3	Complexity	1/9	1/9	1	1/3	1/5	3%
4	Duration	1/3	1/5	3	1	3	12%
5	Configurability	1/5	1/3	5	1/3	1	9%
						Total	100%

		1	2	3	4	5	**Criteria Weights**
		Engagement	Substantive	Complexity	Duration	Configurability	
1	Engagement Level	1	3	5	7	5	45%
2	Substantive Learnin	1/3	1	9	7	7	35%
3	Complexity	1/5	1/9	1	3	7	11%
4	Duration	1/7	1/7	1/3	1	5	7%
5	Configurability	1/5	1/7	1/7	1/5	1	3%
						Total	100%

		1	2	3	4	5	**Criteria Weights**
		Engagement Le	Substantive	Complexity	Duration	Configurability	
1	Engagement Level	1	9	5	9	9	62%
2	Substantive Learning	1/9	1	1	3	5	13%
3	Complexity	1/5	1	1	3	5	15%
4	Duration	1/9	1/3	1/3	1	7	7%
5	Configurability	1/9	1/5	1/5	1/7	1	3%
						Total	100%

		1	2	3	4	5	**Criteria Weights**
		Engagement	Substantive	Complexity	Duration	Configurability	
1	Engagement Level	1	5	1	1	3	33%
2	Substantive Learnin	1/5	1	1	1	1	14%
3	Complexity	1	1	1	1	1	19%
4	Duration	1	1	1	1	1	19%
5	Configurability	1/3	1	1	1	1	15%
						Total	100%

AHP Evaluation of Alternatives for Dice Game

Evaluation of alternatives based on Engagement

		1	2	3	4		
		Face-to-face	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face	1	5	7	3	3.20	59%
2	Existing Online	1/5	1	1/4	1/3	0.36	7%
3	New Prototype	1/7	4	1	3	1.14	21%
4	iPad App	1/3	3	1/3	1	0.76	14%
					Total	5.464	100%

Evaluation of alternatives based on substantive learning

		1	2	3	4		
		Face-to-face	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face	1	5	5	3	2.94	55%
2	Existing Online	1/5	1	1/4	1/3	0.36	7%
3	New Prototype	1/5	4	1	5	1.41	26%
4	iPad App	1/3	3	1/5	1	0.67	12%
					Total	5.385	100%

Evaluation of alternatives based on complexity

		1	2	3	4		
		Face-to-face	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face	1	1/3	1/3	1	0.58	13%
2	Existing Online	3	1	1	1/3	1.00	23%
3	New Prototype	3	1	1	1/3	1.00	23%
4	iPad App	1	3	3	1	1.73	40%
					Total	4.309	100%

Evaluation of alternatives based on duration

		1	2	3	4		
		Face-to-face	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face	1	1/5	1/5	1/3	0.34	7%

2	Existing Online	5	1	1	1/3	1.14	23%
3	New Prototype	5	1	1	1/3	1.14	23%
4	iPad App	3	3	3	1	2.28	47%
					Total	4.892	100%

Evaluation of alternatives based on configurability

		1	2	3	4		
		Face-to-face	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face	1	5	3	3	2.59	54%
2	Existing Online	1/5	1	1	1	0.67	14%
3	New Prototype	1/3	1	1	1	0.76	16%
4	iPad App	1/3	1	1	1	0.76	16%
					Total	4.778	100%

	Engagement Level	Substantive Learning	Complexity	Duration	Configurability
Face-to-face Version	0.5858	0.5465	0.1340	0.0695	0.5420
Existing Online	0.0658	0.0667	0.2321	0.2323	0.1399
New Prototype	0.2094	0.2626	0.2321	0.2323	0.1590
iPad App	0.1391	0.1242	0.4019	0.4660	0.1590

	Criteria Weights
Engagement Level	0.2934
Substantive Learning	0.3743
Complexity	0.1409
Duration	0.0662
Configurability	0.1251

	Net Score
Face-to-face Version	0.4677
Existing Online	0.1099
New Prototype	0.2277
iPad App	0.1947

AHP Evaluation of Alternatives for Lampshade Game

Evaluation of alternatives based on Engagement

		1	2	3	4		
		Face-to-face Version	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face Version	1	7	3	3	2.82	56%
2	Existing Online	1/7	1	3	3	1.06	21%
3	New Prototype	1/3	1/3	1	1	0.58	11%
4	iPad App	1/3	1/3	1	1	0.58	11%
						5.037	100%

Evaluation of alternatives based on substantive learning

		1	2	3	4		
		Face-to-face Version	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face Version	1	3	1	1	1.32	30%
2	Existing Online	1/3	1	1/3	1/3	0.44	10%
3	New Prototype	1	3	1	1	1.32	30%
4	iPad App	1	3	1	1	1.32	30%
						4.387	100%

Evaluation of alternatives based on complexity

		1	2	3	4		
		Face-to-face Version	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face Version	1	7	3	3	2.82	52%
2	Existing Online	1/7	1	1/5	1/3	0.31	6%
3	New Prototype	1/3	5	1	3	1.50	28%
4	iPad App	1/3	3	1/3	1	0.76	14%
						5.385	100%

Evaluation of alternatives based on duration

		1	2	3	4		
		Face-to-face Version	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face Version	1	3	1/3	1/3	0.76	15%
2	Existing Online	1/3	1	1/5	1/5	0.34	7%
3	New Prototype	3	5	1	1	1.97	39%
4	iPad App	3	5	1	1	1.97	39%
						5.036	100%

Evaluation of alternatives based on configurability

		1	2	3	4		
		Face-to-face Version	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face Version	1	5	5	5	3.34	63%
2	Existing Online	1/5	1	1	1	0.67	13%
3	New Prototype	1/5	1	1	1	0.67	13%
4	iPad App	1/5	1	1	1	0.67	13%

5.350	100%

	Engagement Level	Substantive Learning	Complexity	Duration	Configurability
Face-to-face Version	0.5593	0.3000	0.5232	0.1509	0.6250
Existing Online	0.2114	0.1000	0.0580	0.0675	0.1250
New Prototype	0.1146	0.3000	0.2777	0.3908	0.1250
iPad App	0.1146	0.3000	0.1411	0.3908	0.1250

	Criteria Weights
Engagement Level	0.2934
Substantive Learning	0.3743
Complexity	0.1409
Duration	0.0662
Configurability	0.1251

	Net Score
Face-to-face Version	0.4383
Existing Online	0.1277
New Prototype	0.2266
iPad App	0.2073

AHP Evaluation of Alternatives Individual Responses (continued)

Evaluation of alternatives based on Engagement

		1	2	3	4		
		Face-to-face Version	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face Version	1	3	1 2/7	1 4/5	1.62	38%
2	Existing Online	1/3	1	3/7	3/5	0.54	13%
3	New Prototype	7/9	2 1/3	1	1 2/5	1.26	29%
4	iPad App	5/9	1 2/3	5/7	1	0.90	21%
						4.329	100%

Evaluation of alternatives based on substantive learning

		1	2	3	4		
		Face-to-face Version	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face Version	1	3 1/2	1 1/7	2	1.68	39%
2	Existing Online	2/7	1	4/7	2/3	0.57	13%
3	New Prototype	7/8	1 3/4	1	1 1/6	1.16	27%
4	iPad App	1/2	1 1/2	6/7	1	0.90	21%
						4.308	100%

Evaluation of alternatives based on complexity

		1	2	3	4		
		Face-to-face Version	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face Version	1	1 1/7	1 2/5	2 1/3	1.39	34%
2	Existing Online	7/8	1	6/7	3/7	0.75	18%
3	New Prototype	5/7	1 1/6	1	1 3/4	1.10	27%
4	iPad App	3/7	2 1/3	4/7	1	0.87	21%
						4.111	100%

Evaluation of alternatives based on duration

		1	2	3	4		
		Face-to-face Version	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**

1	Face-to-face Version	1	7/9	3/4	6/7	0.84	20%
2	Existing Online	1 2/7	1	1 1/3	2	1.36	33%
3	New Prototype	1 1/3	3/4	1	2	1.19	29%
4	iPad App	1 1/6	1/2	1/2	1	0.73	18%
						4.126	100%

Evaluation of alternatives based on configurability

		1	2	3	4		
		Face-to-face Version	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face Version	1	6	2/3	1 1/2	1.57	31%
2	Existing Online	1/6	1	1/7	3/4	0.37	7%
3	New Prototype	1 1/2	7	1	3 1/2	2.46	48%
4	iPad App	2/3	1 1/3	2/7	1	0.71	14%
						5.103	100%

	Engagement Level	Substantive Learning	Complexity	Duration	Configurability
Face-to-face Version	0.3750	0.3904	0.3381	0.2038	0.3067
Existing Online	0.1250	0.1333	0.1831	0.3298	0.0716
New Prototype	0.2917	0.2684	0.2673	0.2882	0.4825
iPad App	0.2083	0.2079	0.2115	0.1781	0.1391

	Criteria Weights
Engagement Level	0.2934
Substantive Learning	0.3743
Complexity	0.1409
Duration	0.0662
Configurability	0.1251

	Net Score
Face-to-face Version	0.3557
Existing Online	0.1432
New Prototype	0.3032
iPad App	0.1979

AHP Evaluation of Alternatives Individual Responses (continued)

Evaluation of alternatives based on Engagement

		1	2	3	4		
		Face-to-face Version	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face Version	1	7	4	6	3.60	61%
2	Existing Online	1/7	1	1/4	1/3	0.33	6%
3	New Prototype	1/4	4	1	4	1.41	24%
4	iPad App	1/6	3	1/4	1	0.59	10%
						5.939	100%

Evaluation of alternatives based on substantive learning

		1	2	3	4		
		Face-to-face Version	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face Version	1	7	5	7	3.96	65%
2	Existing Online	1/7	1	1/3	1/3	0.35	6%
3	New Prototype	1/5	3	1	3	1.16	19%
4	iPad App	1/7	3	1/3	1	0.61	10%
						6.084	100%

Evaluation of alternatives based on complexity

		1	2	3	4		
		Face-to-face Version	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face Version	1	5	3	4	2.78	52%
2	Existing Online	1/5	1	1/5	1/4	0.32	6%
3	New Prototype	1/3	5	1	3	1.50	28%
4	iPad App	1/4	4	1/3	1	0.76	14%
						5.355	100%

Evaluation of alternatives based on duration

		1	2	3	4		
		Face-to-face Version	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face Version	1	1/4	1/5	1/3	0.36	7%
2	Existing Online	4	1	1/3	3	1.41	26%
3	New Prototype	5	3	1	5	2.94	55%
4	iPad App	3	1/3	1/5	1	0.67	12%
						5.385	100%

Evaluation of alternatives based on configurability

		1	2	3	4		
		Face-to-face Version	Existing Online	New Prototype	iPad App	Geometric Mean	**Alternative Scores**
1	Face-to-face Version	1	9	7	9	4.88	70%
2	Existing Online	1/9	1	1/4	1/4	0.29	4%
3	New Prototype	1/7	4	1	4	1.23	18%
4	iPad App	1/9	4	1/4	1	0.58	8%
						6.975	100%

	Engagement Level	Substantive Learning	Complexity	Duration	Configurability
Face-to-face Version	0.6062	0.6502	0.5198	0.0667	0.6996
Existing Online	0.0556	0.0583	0.0591	0.2626	0.0414
New Prototype	0.2381	0.1904	0.2793	0.5465	0.1763
iPad App	0.1001	0.1010	0.1419	0.1242	0.0828

	Criteria Weights
Engagement Level	0.2934
Substantive Learning	0.3743
Complexity	0.1409
Duration	0.0662
Configurability	0.1251

	Net Score
Face-to-face Version	0.5865
Existing Online	0.0690
New Prototype	0.2387
iPad App	0.1058

APPENDIX B: PRE AND POST-TEST QUESTIONNARE

Pre-Post Survey
There can be more than one correct answer for each question.

Please mark the appropriate answer:

1. Please mark all that relates to Lean Production
   a. Flexible equipment with fast setups
   b. Use of visuals to communicate within the production environment
   c. Quality at the source
   d. Pull system
   e. Build to Order
   f. All of the above

2. Please mark all that relates to Mass Production
   a. Division of labor
   b. Assembly lines
   c. High production volumes
   d. Low product variety
   e. All of the above

3. Please mark all that relates to Craft Production mean
   a. Built to order
   b. Low volume production
   c. High product variety
   d. Custom built
   e. All of the above

4. Which of the following makes a company leaner?
   a. Mass production of goods
   b. Running all machinery at their full capacity all the time
   c. Forecasting demand to build
   d. Single skilled operators
   e. All of the above

f. None of the above

5. Which of the following production technique yields the highest effective throughput in an uncertain market environment
   a. Build to Stock
   b. Push
   c. Lean
   d. Mass
6. All of the aboveWhich of the following describes a push system?
   a. A system that starts with the push of a button
   b. Build to stock
   c. Just-in-Time Production
   d. Building based on forecast
   e. b and d
   f. none of the above

7. What is the purpose of a kanban?
   a. To communicate a message from upper management to shop floor
   b. A work order from upstream to downstream operations
   c. To forecast customer demand
   d. To communicate a work order from downstream to upstream operations
   e. c. and d.
   f. None of the above
8. Which of the following is a possible waste category?
   a. Scrapped Materials
   b. Setup time
   c. Rework
   d. Space
   e. All of the above
9. What is a standard work?
   a. A term used in lean production for boring work
   b. A term used in lean production for wasted work
   c. Work that has ISO 9000 Standards compliance
   d. Documentation of best practices and process steps at an operation.
   e. None of the above
10. What is a shadow board?
   a. A board where shadows are used to make shows
   b. A board to hang tools
   c. A board that makes shade
   d. All of the above