Learning to Design Experiments Using Computer Simulations*

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Using software to simulate experiments is a very useful tool in the fields of quality engineering. This allows engineers to acquire the ability to identify the key parameters of a product or process. In this paper, a design of experiments is applied to a helicopter prototype problem which resembles a general engineer problem. This example illustrates the powerfulness of this statistical tool when it is utilized in conjunction with engineering knowledge. In addition, this points out the value of this technique in the industry. Furthermore, with this simulation, the students learn this statistical method developing their own project. Other simulator has been developed to contribute in learning design of experiments: A cannon with several different control factors as well as noise factors. These simulators are two modules of an educational material developed for the teaching and learning of statistics. From our experience, this material and its modules have improved the understanding of statistical concepts and increased the motivation to learn more about it.

Keywords: engineering education; experimental design; helicopter simulator; factorial design

1. Introduction

The course of design of experiments is a common component of the curriculum of industrial engineering. When recent graduates get a job in the industry, it is observed they lack the ability to perform an experiment using design of experiments subject. This course frequently has a technical approach. Nevertheless, students need to have a solid knowledge and command of various statistical concepts, e.g., probability calculations, probability distributions, hypothesis tests and development of statistical models. Accordingly, we have developed an innovative and visual-attractive didactic software which includes animations and simulations. This software looks to contribute in the improvement of the teaching-learning activities in post-secondary education. In this paper, we present a set of mechanisms and prototypes to illustrate and encourage several concepts of statistics and probability.

This visual approach for education considers the idea of learning by playing and doing-yourself. A collection of animations includes the classical probability games, e.g., coin flipping, dice, coin-dice, roulette, bag of marbles, trees, etc. These activities are linked to the understanding of different concepts, for instance, the probability distributions. In the same approach, the probability distributions have been exposed in a graphical manner so that the learner has a clear perception on the roles of density and cumulative probability. These animations allow to increase the interest of the students in this subject as well as to explore new ideas by interacting with the software [1].

Furthermore, in the experimental module, two simulators have been developed. These simulators emulate two problems similar to a manufacturing process in industrial engineering, mechanical, etc. One of these simulators reproduces the traditional paper helicopter project. This project consists of a helicopter which falls from a given altitude, which was originally presented by Box and Liu [2]. The helicopter has a couple of helixes attached to a body. The control factors are the length, width and angle of the helixes, the type of paper, the body height and the weight attached to the end of the body. The noise factors are the environment humidity and temperature. The altitude of deployment is also considered. The response variable is the flying time.

The second simulator is a cannon with several control factors: shoot force, angle, length and height of the cannon, type and weight of the ball. There are also three noise factors: temperature, humidity and wind velocity. Other factor to bear in mind is the target distance. Three response variables are considered while the objective of this prototype is to hit a target.

Hence, the students can play in planning various projects to enable them to investigate about these prototypes. Using this dynamic, the learners will be able to perform several experiments with different objectives. In addition, the students can also create mathematical models to study the performance of each device. Accordingly, a collection of modules to design experiments and build models has been developed. We believe that this software will create an innovative procedure in the teaching and learning of design of processes using statistical and

probability concepts. Thus, this material contributes in the education of engineers.

2. Considerations in the improvement of teaching and learning

The proposed learning process poses the developing of experiments using simulations. These are used to study the concepts of statistical techniques, which involve design, and analysis of experiments. The simulations allow the student to learn the ideas of industrial innovation, for instance, the developing of a new engineering system as results of a research based on a sequence of experiments. The statistical work consists of studying factorial designs of first and second orders. Hence, we can obtain the influence of the control factors as well as the noise factors. To identify the influence of the factors, it is necessary to utilize the statistical procedure of hypothesis testing. This statistical concept is illustrated with the proposed educational material. The goal of the design is to maximize the flight time. The helicopter is released from a fixed height.

On the other hand, in the project for the improvement in the manufacturing of a product, the engineer must have good knowledge of the process. In this learning stage, the engineer has to perform a characterization of the process applying quality engineering techniques such as design of experiments. In this learning process, the engineering analysis and statistical analysis are joined together. In the section Methodology, both analyses are described but we emphasize in the educational part of statistics. Hence, the student will be able to understand the statistical concepts applied in the solution of engineering problems.
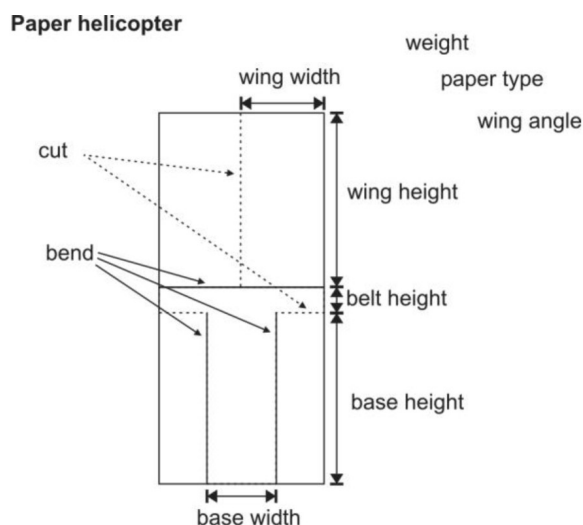
3. Methodology

3.1 Helicopter engineering analysis

The paper helicopter project has been used to teach design of experiments since early 1990's. Figure 1 illustrates the layout of the paper helicopter and its control factors. This problem has been very popular, as it resembles most of the quality engineering problems (e.g., multifactor experiment, nonlinear model). Also, it has been very convenient as it is simple and inexpensive. Furthermore, this project is very interesting as it combines statistical and engineering knowledge [3]. Moreover, to successfully collect and model the data, it is important to understand the physical process. Accordingly, we describe the mechanical system of the paper helicopter. The system is subjected to vertical and horizontal forces. The later only affects the spinning of the helicopter and can be ignored in the analysis while the former has two components acting in opposition: the gravity force and the drag force. The down force, F_d, is given by the well-known equation:

$$F_d = mg$$

where m is the mass of the helicopter and g is the gravity constant. Furthermore, the upward force, F_u, of the helicopter moving through the air is given by:

$$F_u = \frac{1}{2}\rho\nu^2 A C_D$$

where ρ is the mass density of the air, ν^2 is the velocity, A is the cross sectional area ($A = \pi(L^2 + W^2)\cos\theta$, where L and W are the length and width of the wing, respectively), C_D is the drag coefficient. Figure 2 illustrates the effects of the air on the wings.
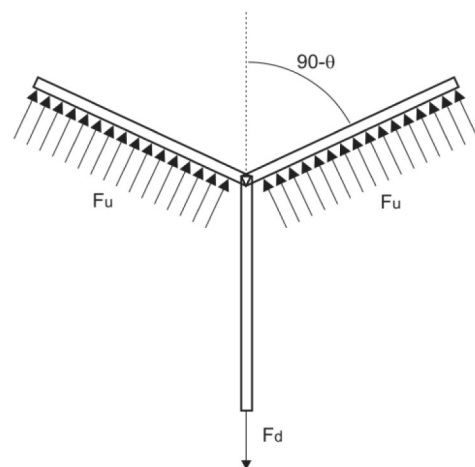

Fig. 1. Paper helicopter layout and its factors.

Fig. 2. Drag forces acting on the helicopter wings.

In order to provide noise parameters, we bear in mind that the mass density of the air, ρ, is affected by the changes of temperature, pressure and humidity. Hence, the density of the air is given by:

$$\rho = \frac{MP}{RT}$$

where M is the molar mass, P is the pressure, R is the universal gas constant, and T is the absolute temperature. If we consider the moment of terminal velocity (i.e., no acceleration), we obtain that:

$$F_u = W_0 \frac{S}{S_0}$$

where W_0 is the weight of the full sheet of paper and S_0 is its area. S is the paper area used to build the helicopter. If we solve for the terminal velocity, we get:

$$\nu^2 = \frac{2W_0 S}{\rho S_0 A C_D} \quad (1)$$

When the helicopter is static, we have that the effective wing area is $A_e = LW$. But as the helicopter spins as it falls, the effective area gets reduced. Hence, the drag force is unknown while S is a known expression of the design factors. Developing Equation 1 by using the design factors and bearing in mind that the drag force will act only on the projection of the wings, we obtain:

$$\nu^2 = \frac{W_0[BH + (2L + B_h)W]}{\rho S_0 C_D LW \cos\theta} \quad (2)$$

where B is the base width, H is the base height and B_h is the belt height. From Equation 2, we notice that to increase the flight time, we need to minimize the base length and height and maximize the area of the wings.

3.2 Helicopter project description

There are six control factors which are used in the Analysis option. Two noise factors are utilized in the Improvement option and permit to perform robust design. The height from where the helicopter is released can also be modified but it remains fixed through the experimentation.

Based on the information provided by the cause and effect diagram given by Fig. 3, six control factors and two noise factors are selected. These factors and their minimum and maximum values are described in Table 1. A simulation is illustrated in Fig. 4. We have selected the control factors and then pressed the Release button. Then, the software shows the animation of the helicopter flying and registers the total flight time. This is a random

variable with a normal probability distribution. Commonly, a simulation of a physical system involves a random component to represent the effects of chance of a real system. This is known as stochastic simulation. By changing the values of the factors, other situations are generated. An orderly modification of these values will generate knowledge about the process. A similar methodology is used in the improvement of process in science and technology. Table 2 describes an experimental design known as fractional factorial design. This is used as a strategy to generate preliminary knowledge about the process. Hence, the experimental sequence will result in a research. Designs such as the central composite design allow building mathematical models of second order thus it is possible to optimize the process. This kind of experiments can also be performed using the tool described in Fig. 6.

The helicopter problem can be utilized in the robust design. Once, the appropriate conditions in the operation of a process are found, it is expected that the variation around these is minimal. The variations are caused by random noise variables related to extreme conditions, such as temperature, humidity, mechanical vibrations, etc. The noise variables play an important role in this kind of design. Thus, the optional Improvement
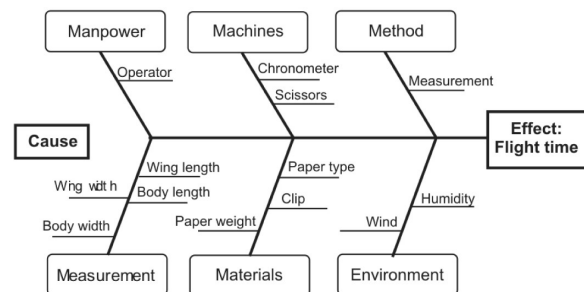
Cause and effect diagram

Fig. 3. Description of the process and product for industrial engineering.

Table 1. Minimum and maximum values for both control and noise factors

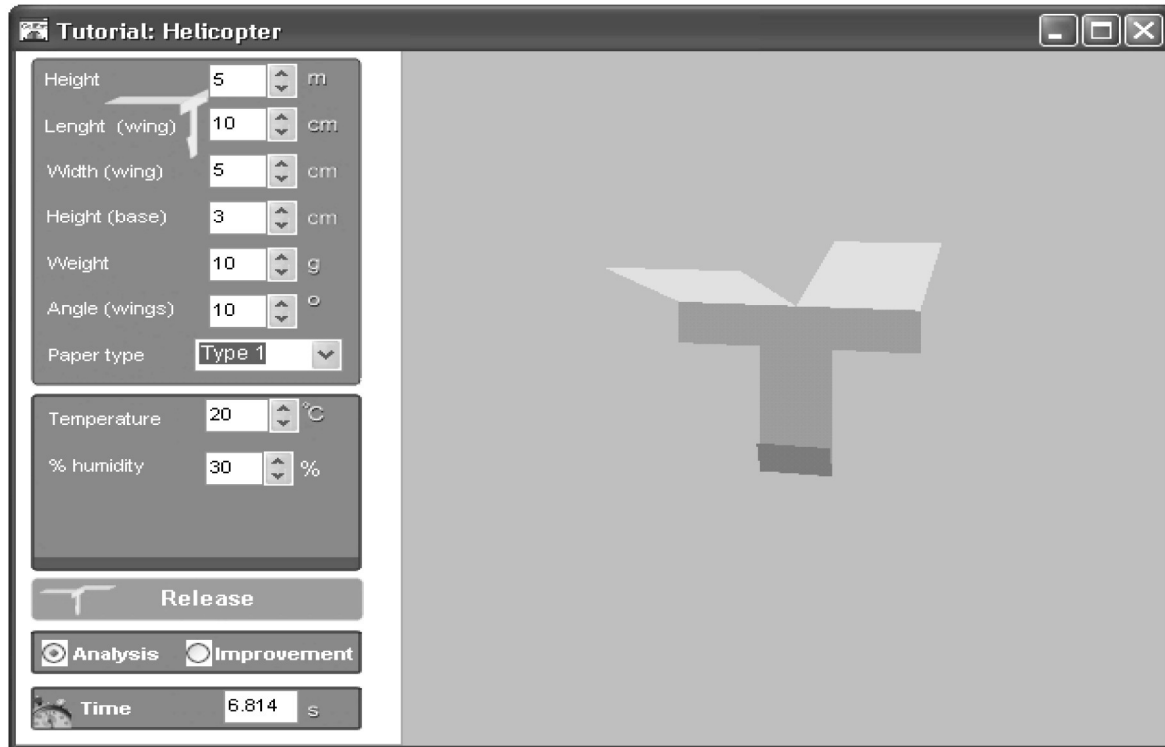| Factors	Range	
	Minimum	**Maximum**
Control		
Wing length (cm)	5	15
Wing width (cm)	3	7
Base height (cm)	1	6
Weight (g)	2	20
Wing angle (°)	0	90
Paper type	1 2 3	
Noise		
Temperature (C)	15	25
Humidity (%)	30	50

Fig. 4. Educational outline to generate the experiment.

Table 2. Values of the levels to carry out the experiment

Control Factors	Low level (1−)	High level (+1)
A: Wing length (cm)	7	12
B: Wing width (cm)	4	6
C: Base height (cm)	3	5
D: Weight (g)	5	15
E: Wing angle (°)	0	90
F: Paper type	1	2

has been considered for the robust design using simulation.

4. Statistical analysis of the helicopter

4.1 Hypothesis testing

The first step of a statistical analysis is to perform a hypothesis testing. For the helicopter project, we are interested in knowing if the factors indeed have an effect in the system. We start by evaluating the effect of the wing length to illustrate how the educational material is utilized to execute a hypothesis test. For the current problem, our alternative hypothesis, $H_1 : \delta_L \neq 0$, consists of the suggestion that there is an influence in the wing length in the flight time while the negation of this give us the null hypothesis. This is formally represented by:

$$H_0 : \delta_L = 0$$
$$H_1 : \delta_L \neq 0 (\delta_L < 0, \delta_L > 0)$$

where $\delta_L = \mu_{15} - \mu_{10}$ which is the difference between the means of the flight time when the helicopter had a wing length of 15 and 10 cm, respectively.

The experimental procedure is as follows:

1. Release the helicopter 30 times with a wing length of 10 cm. We use the simulator shown in Fig. 4. We record the flight times and calculate the mean and variance.
2. Similarly, we do the same experiment for a helicopter with a wing length of 15 cm.
3. Then we obtain the difference $\hat{\delta}_L = \bar{y}_{15} - \bar{y}_{10} = 7.68 - 6.72 = 0.56$, where $\hat{\delta}_L$ is an estimator of minimum squares δ_L.
4. Finally, this difference is compared against the threshold illustrated by Fig. 5. If it falls on the left side, the null hypothesis is not rejected, i.e., we say the factor has no effect. On the other hand, the null hypothesis is rejected and we conclude that the factor has effect. In this case as $\hat{\delta}_L = 0.56 > 0.18 =$ threshold then the null hypothesis is rejected and we say that the wing length has influence in the process performance.

To generate the graphic illustrated in Fig. 5 we did the following: we considered the null hypothesis equal to zero; we set an alternative hypothesis greater than zero. It has been proposed that $\delta_L = 0.3$. With the calculation of the variance, we estimate the standard error of the random variable $x = \hat{\delta}_L$. With the gathered data, we obtain that the
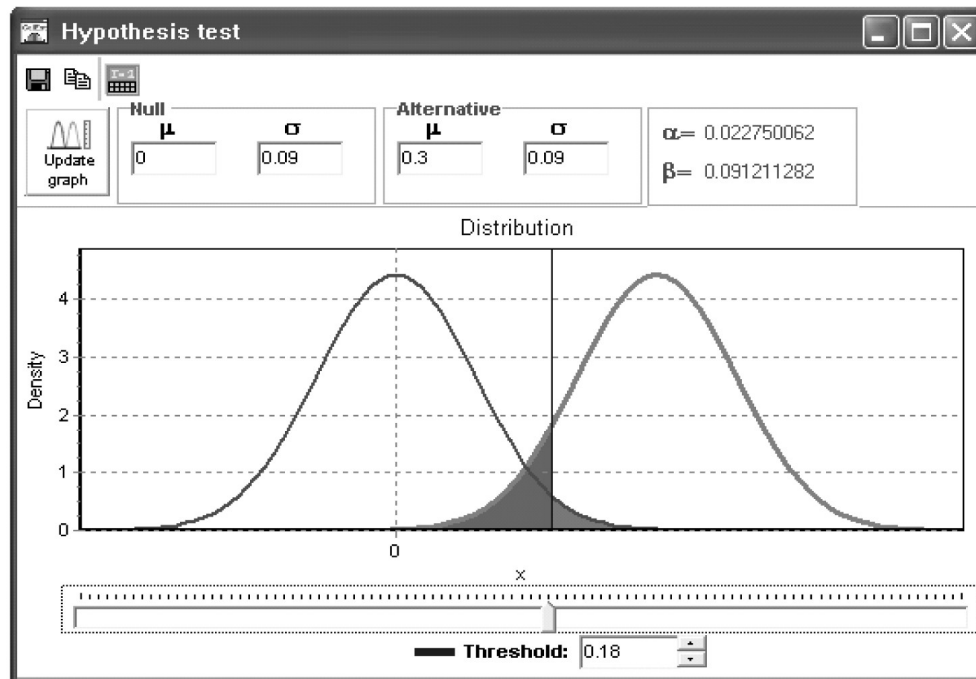
Fig. 5. Description of the hypothesis test concept.

standard error is 0.09. Then the threshold is fixed based on the probability of rejecting the null hypothesis when it is true, denoted by α, which is the significance level. For our current hypothesis, we have $\alpha/2 = 0.25$, which is approximated by the graphic to 0.0227.

The strategy of teaching/learning illustrated in Fig. 5 has the statistical hypothesis approach. This application helps the engineer to visually understand the procedure involved in this statistic method. Moreover, it allows the user to keep testing different situations. The approach developed here goes towards the concept of learning through play and its implications for engineering education.

4.2 Design of experiments

After reviewing the problem statement, the next step in a design of experiments is the brainstorming of input factors and the responses. In the helicopter modeling problem, the output of interest is the flight time. The Cause and Effect or fishbone diagram in Fig. 3 provides an organized approach for collecting engineering knowledge of potentially important input factors [4]. For the helicopter, the input factors range from the different settings on the helicopter to variability in the operator method, see Table 1. Brainstorming these variables involves both general engineering knowledge and common sense.

For the experiment, each of the chosen input factors must have high and low value (see Table 2). The design to be implemented is a two level design, i.e., all input factors have only two test settings as shown in Fig. 6. The top setting will be designated as the high +1 and the bottom setting as low and coded –1, see [5].

Design of experiments involves purposeful changes of inputs of a process in order to observe the corresponding changes to the response. One of the objectives of design of experiments is to model the process using a minimum number of experimental resources. The helicopter can be modeled using an eight run with two level design matrix, see Table 3. Six input factors will be analyzed individually and interactively for their effect on the flight time of the helicopter.

The design matrix is generated using the options given in Fig. 6, with the fractional factorial design 2^{6-3}. Table 3 describes the design and its results. Using the design tool shown in Fig. 6, the row 2 is selected (i.e., 8 runs) and the column 5 (i.e. 6 factors), with two replicates. Then we click on Continue. A worksheet is created. Using the data obtained from the experimentation, we fill this worksheet. The data source is the proposed paper helicopter simulator described in Fig. 4. Hence, every engineer can perform his own experimentation. This is a contribution of the described educational material which focuses on improving the activities of teaching/learning. Each run (column 1) is randomized as shown in column 2 (replicate 1, replicate 2). The height of release was fixed to 5 meters.
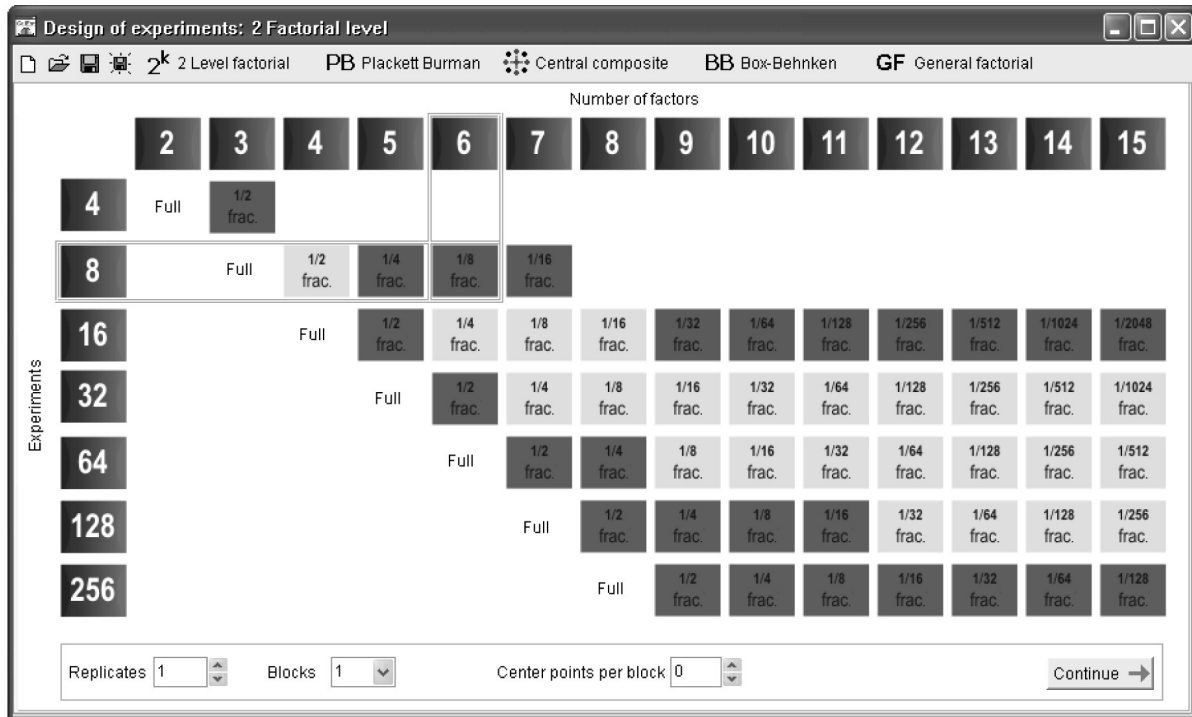
Fig. 6. The main screen describes the design of experiments in two levels.

Table 3. Design Matrix and Response Values

Run	Randomize	A	B	C	D	E	F	Y1	Y2
1	4,2	−1	−1	−1	1	1	1	6.01	5.95
2	6,7	1	−1	−1	−1	−1	1	6.96	7.04
3	1,6	−1	1	−1	−1	1	−1	6.58	6.71
4	5,1	1	1	−1	1	−1	−1	7.11	6.92
5	3,5	−1	−1	1	1	−1	−1	6.24	5.94
6	7,8	1	−1	1	−1	1	−1	6.86	6.70
7	8,4	−1	1	1	−1	−1	1	6.86	6.75
8	2,3	1	1	1	1	1	1	6.66	6.63

Once the experimental data has been captured in the worksheet, we click the Analyze button to generate a statistical report. A summary of the obtained statistical analysis is given in Table 4. This is similar to the analysis given in the hypothesis test. In other words, in each case, the effect of each factor will be observed.

This effect is the difference between the means of high level minus the low level: $\hat{\delta}_{factor} = \bar{y}_{high} - \bar{y}_{low}$. In this case, the threshold to be used comes from the t-Student distribution, i.e., $t(dof, \alpha/2)$, where dof = number of runs-1-number of parameters. For the helicopter project, the threshold is given by $t(gl, \alpha/2) = t(9, 0.025) = 2.264$ or $t(9, 0.025) = -2.264$.

The influence of the factors on the paper helicopter flight time is significant (S), if $t_0 > 2.264$ or $t_0 < -2.264$. Accordingly, the factors Wing Length, Wing Width, Height Base and Wing Angle are relevant. Based on this information, it is possible to build the model that describes the flight time. The

estimated parameters corresponding in the factorial design of two levels are: $\hat{\beta}_{factor} = \hat{\delta}_{factor}/2$. Thus the model is given by:

$$\hat{y} = 6.62 + 0.24A + 0.16B - 0.19D - 0.11E.$$

Hence, if the wing length and width increases, the flight time does too. Also, if the height of the base decreases, the flight time increases. The angle of the wings should be 0 and the physical effect of releasing the helicopter has been described above.

4.3 Cannon engineering analysis

Similarly to the helicopter, we are going to evaluate the mechanical system before beginning its statistical analysis. The cannon problem is defined as a two dimensional motion of an object thrown in a gravitational field. The goal of the system is to hit a target, which is at a distance defined by the user. Figure 7 illustrates the simulation module for the cannon system.

The system is subjected to vertical and horizontal forces. The former are given by the resistance presented by the air as well as the force applied by the wind to the ball. The horizontal components are the gravity and horizontal drag forces. The distance traveled is given by:

$$d = \frac{\nu \cos \theta}{g} \left(\nu \sin \theta + \sqrt{(\nu \sin \theta)^2 + 2gy_0} \right) \quad (3)$$

where θ is the thrown angle, y_0 is the initial height, v is the velocity at which the ball is launched. The flight time is described by:

$$t = \frac{d}{\nu \cos \theta} \quad (4)$$

Considering the effects of the air, we have the mass density:

$$\rho = \frac{\rho_{air}}{R_d T} + \frac{\rho_s}{R_s T}$$

where R_d and R_s are the specific gas constant for dry air and water steam respectively. Then, we have the drag force:

$$F_d = 0.5 \rho \nu_{ball}^2 A C_D$$

where A is the characteristic frontal area, C_D is the drag coefficient, and the wind force applied to the flying ball:

$$F_W = 0.5 \rho \nu_{wind}^2 A C_D$$

then we obtain the equation for the distance including the noise factor of temperature, humidity and wind velocity:

$$d_f = \nu t + 0.5 \rho A C_D (\nu_{ball}^2 + \nu_{wind}^2) t^2 / 2m$$

where the initial velocity is given by:

$$v_0 = \sqrt{(2Fl_{cannon})/m_{ball}}$$

where F is the throw force, l_{cannon} is the length of the cannon and m_{ball} is the mass of the ball.

4.4 Cannon statistical analysis

We utilize the design of experiments approach to provide solution to an elementary engineering problem: a projectile trajectory using a cannon. In this case, three input factors will be analyzed individually and interactively for their effects on the distance of the ball. In Table 5, the factors and their levels are described.

The cannon can be modeled using an eight run, two level design matrix (see Table 6). To perform our experiment we utilize the prototype described in the Fig. 7. A distance objective is used to 5 meters. In this problem, we are interested in studying interaction among effects. These are defined in Table 6. In the study of the cannon, the designs presented in Fig. 6 are employed. In an exploratory study, we perform a factorial design with two levels. For the process of optimization, the composite central and Box-Behnken designs are appropriate.

The important of these examples is that the engineer uses factors that give place to his imagination. As starting point, these prototypes allow the learner to recognize a learning process through an experimental design. Hence, he/she will be able to understand and implement an improvement methodology to an industrial process.

4.5 Improvement

This article could be expanded several pages to describe with details how to implement the learning experience in the improvement of a process and the possible scenarios using both the helicopter and the cannon. Nevertheless, we present a brief guide of some typical activities so you can continue with these prototypes in the improvement of a process. For instance, flowcharting the process to understand it better; collecting data to assess the current performance, use the tool for exploring data, numerical summaries, testing hypotheses, and experimental design (see Fig. 6); Identifying factors where the process could be fundamentally improved [6].

5. Assessment of learning using the helicopter and the cannon

In order to evaluate experience in the learning process in industrial engineering topics through thematic design of experiments, there have been two practices with students applying the helicopter and cannon projects as teaching technique to learn through playing. In one of them turned to an examination and the other to a survey. In the first case, ten students involved, who have studied the

Table 4. Results and analysis obtained of the experiment.

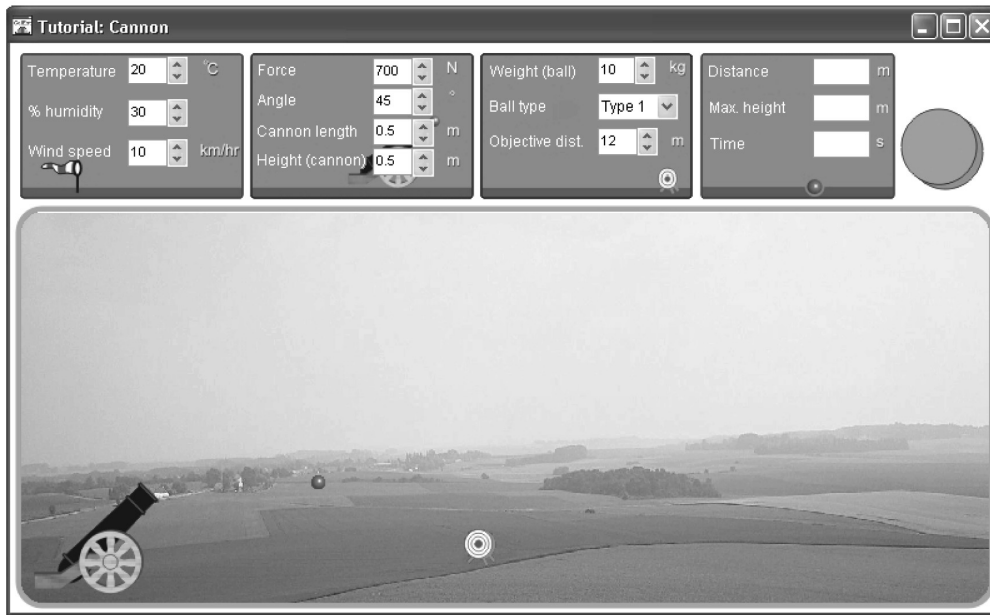| Factors	A	B	C	D	E	F
Effects $\hat{\delta}_{factor}$	0.48	0.32	–0.08	–0.38	–0.22	–0.03
Parameters $\hat{\beta}_{factor}$	0.24	0.16	–0.04	–0.19	–0.11	–0.015
The test statistic t_0	8.85	5.81	–1.48	–6.92	–3.96	0.66
Influences	S	S	NS	S	S	NS

Fig. 7. Educational outline to generate the experiment using a cannon.

subjects of statistical methods and experimental design.

We conducted an evaluation of these projects, with the purpose of knowing the acquired experience inside the classroom and to have evidence in the learning. This was to make a preliminary examination of basic concepts of statistical in design of experiments after using the prototypes helicopter and cannon. We returned to apply the same initial assessment and compare results. Each exam has 20 questions and we verify the homogeneity of both tests. The grades obtained are shown in Table 7. The rating defined as the number of correct answers by 20.

With the purpose to know the impact of learning material, we propose the following hypothesis: On average, the students that used the educational material, improved in their knowledge in a significant way. Statistically, the hypothesis is expressed by: $H_1 : \mu_A > \mu_B$. This was highly significant, with $p < 0.000001$ the result indicates that the material helped students improve their knowledge in the field of experimental design.

We can also evaluate the efficiency of the material using other techniques for measuring quality. For example, in this case, the performance was measured using the desirability function concept, this is defined by the following expression:

$$d = \begin{cases} \frac{NCAA - NCAB}{MNCA - NCAB} & \text{if } NCAA > NCAB \\ 0 & \text{if } NCAA < NCAB \end{cases}$$

Where $NCAB$ is the number of correct answers before, $NCAA$ number of correct answers after and $MNCA$ the maximum number of correct answers by using the prototypes. If d is close to 1,

Table 5. Factors and values of the levels to carry out the experiment

Control Factors	Low level (1–)	High level (+1)
A: Force (Newton)	600	700
B: Angle	30	60
C: Cannon Length	0.5	0.8

Table 6. Design Matrix to carry out the experiment

Run	A	B	C	AB	AC	BC	Y1	Y2
1	–1	–1	–1	1	1	1	6.11	5.87
2	1	–1	–1	–1	–1	1	7.53	7.20
3	–1	1	–1	–1	1	–1	5.72	5.41
4	1	1	–1	1	–1	–1	6.32	6.12
5	–1	–1	1	1	–1	–1	9.29	9.47
6	1	–1	1	–1	1	–1	11.26	10.13
7	–1	1	1	–1	–1	1	8.95	8.86
8	1	1	1	1	1	1	9.75	10.29

Table 7. Ratings on the 20 questions and the value of desirability

	1	2	3	4	5	6	7	8	9	10	$\bar{X}$	S
Before	4	3.5	5	3	4	3	2	4.5	2.5	3.5	3.5	0.91
After	7.5	7.5	9.5	7	8	6.5	9.5	9	8	9	7.75	1.16
Desirability	0.58	0.62	0.90	0.57	0.67	0.50	0.94	0.82	0.73	0.85		

Table 8. Student response to the survey

Prototype	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
Helicopter	225	237	240	242	235	235	225	227	239	240
	0.918	0.967	0.979	0.987	0.959	0.918	0.927	0.927	0.976	0.979
Cannon	237	239	225	241	240	242	233	238	243	230
	0.967	0.976	0.918	0.984	0.980	0.988	0.951	0.971	0.992	0.939

knowledge is highly desirable, in this situation we can say that the student learns by itself. Clearly, if d is greater than zero shows that each individual has a better use through play. The global desirability in this study were obtained by the geometric mean, this is: $D = (d_1 d_2 ... d_{10})^{1/10}$. This value shows a good performance in the students who participated in this project.

Later on, we carry out two workshops of 10 hours each one, with the focus of elaborating a project as didactic technique to learn through the game. In them, several students participated, when concluding the workshops, a survey was applied with the purpose that they evaluated the material used. The measurement in this case arises in the context of a subjective measure since it is considered situations that respond to the trial and personal expectations of students. It assigns a numerical value expressed by the respondent's trial. Using these numbers, we perform a statistical analysis. The evaluation we propose 10 questions and were asked to rate from 1 to 7. This applied to 35 students. Then they answered the survey. The level of questions is: Scale 1: None, 2: Very little, 3: Little, 4: Regular, 5: Well, 6: Very well, 7: Excellent. See [7, pp 137-157]. List learning variables:

V1: Have ease of operation and it allows to organize ideas and concepts.
V2: Motiva to learn.
V3: It facilitates the acquisition of knowledge.
V4: It is useful to learn by playing.
V5: Meets expectations as learning material.
V6: The display is attractive, innovative and friendly.
V7: Allows you to interact with engineering processes.
V8: It is appropriate to learn himself.
V9: Let's learn how to design and conduct experiments.
V10: Build skills to analyze experimental results.

Assessment, the maximum response value is 245 if all answers are 7, and the minimum is 35 if all answers are 1. In order to describe the results of the survey, we chose the easiest way to obtain the views of students, taking the total numerical value of the response of each variable and divided by 245. For example, in the first case 20 marked the scale of 7, 60 the scale of 6 and 25 the scale of 5, so the total is 225. The summary of survey results is showed in Table 8.

One can see that in both evaluations, the results are good to use the helicopter and cannon projects to carry out practical by means of experiments and give rise to the activity of learning through play. These are justified because the teacher uses the exposition as a teaching method and it creates a passive attitude of the student. Students learn through lecture notes and exercising, there is practically no activity of learning through play. In some cases is used for experiments that exist on the Internet but do not arise in a dynamic way, or are related to industrial engineering problems, the visual work is not given.

There were some individual interviews with students after completing practice and participation in workshops; they commented that they had been facilitated to understand the design concepts and its relationship with industry. Guide them in the procedure for engineering projects operating different factors of a process using experimental design issues and identify which ones are important for improving a process. Also became clear concepts of probability distributions, statistical hypothesis testing, among others.

6. Conclusions

In this work, we have shown two approaches to solving an elementary engineering problem. Both approaches were a blend of statistical concept with

engineering knowledge. To accumulate data this experimental design required several hours of work. These case studies show that design process can greatly enhanced by a statistical analysis and that this results increased productivity and reduced design time. Furthermore, the described technology development is presented as a package which uses computer-aid animations and simulations. This development is a new, visually-appealing tool that benefits in the learning, teaching and application of concepts of statistics and probability. On one hand, it gives elements to the teachers to explain different topics in a more enjoyable manner and straightforward to understand. It also provides to the teacher the option of going deeper into the subjects. Its visual environment and animations not only allows but also encourages the student to explore and learn by doing-it-yourself using the auxiliary practice material of the package. The material helps students to understand clearly the concepts, motivate them to learn more and explore by themselves. This software application serves as a supporting material for a better understanding of some concepts as well as a tool to solve problems from different books of statistics. The animations and simulations can also be used to introduce elementary and secondary students to data processing.

A key part of this development is given in the computer knowledge and skills applied to explain and develop the concepts and results in the teaching of statistics and probability. This project has been developed with advanced programming techniques which integrate a collection of resources (e.g., animations, graphics, and simulations) to aid in the teaching/learning of statistics and probability concepts. This technological development, named Cal-Est, runs on Windows XP, Vista and 7 operating systems.

From experience, we know there are several difficulties to convey different concepts in statistics and probability and the students understand them. Utilizing this software application has provided a greater ease in the understanding of concepts and motivate learning these fields. Students who were struggling to understand or/and showed lack of interests have been captivated by the activities as well as by the friendly interface. This is important as the goal is to help students to learn statistics, no how to use a software.

The survey allowed us to confirm that teaching through the development of projects using these prototypes as a means of simulation, enables the student to become directly involved in solving problems and understand the essence of process improvement.

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