INTERACTION BETWEEN ACADEMIA AND INDUSTRY TO BUILD STATISTICAL CAPACITY AMONG INDUSTRIAL-ENGINEERING STUDENTS

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ABSTRACT

One of the aims of this work is to highlight the need for connecting the practice and theoretical studies of industrial engineers. One reason for this need is the fact that students tend to graduate without proper preparation for practice, spreading thus a bad reputation of statistics and its potential, and even affecting students' dispositions and motivation towards the study and applications of statistics. This paper presents the results of a study conducted at two higher-education institutions in Mexico. The industrial engineering students who participated were introduced to a multivariate statistics course, one in a traditional way and the other through a problem-solving approach embedded within an industrial environment. The didactic intervention in both groups and the problems used to evaluate them are described. The results show that the experimental students had a significant increase in their qualifications and a lower variance in their performance. From our study we can suggest that a university education in close connection with applications in an industrial environment significantly improves the students' education. This teaching experiment provides students with opportunities to experience the genuine character of statistics as an applied field, giving meaning to the statistical techniques learnt in the classroom. It is one way to make the education in statistics more apt to the demand from outside and by the same time it enables the students to really understand statistics.

Keywords: *Statistics education research; Industrial statistical skills; Cooperation between industry and academia*

1. INTRODUCTION

Industrial engineers need sound statistical knowledge in order to be able to carry out the processes commonly used in industry, such as quality measurement and control or regression analyses to investigate possible relationships between variables in an industrial system. However, research and practical experience show that the statistical knowledge of industrial engineers often is insufficient to solve manufacturing and quality problems by adequate statistical techniques. This deficit in the statistical education of industrial engineers is partly due to the fact that undergraduate statistics courses tend to focus on probability problems that emphasize mathematical aspects rather than on techniques that are actually useful in practice.

Different approaches have been suggested to address this gap between instruction and practice in the university education of future industrial engineers. Some of them make use of

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digital technologies to model and simulate structures and processes within a factory (for example, Miller & Bures, 2015), while others suggest an approach based on interaction and cooperation with the industry (Bayless, 1999; McKinnis, McNamara, Kuczec & Salvendy, 2001).

Industrial engineers in practice, as well as those in the training stage at university, have to make intensive use of statistical techniques and strategies, mainly in the design and analysis of experiments, as well as in the application of regression techniques or univariate and multivariate descriptive statistics. Such facts are not accidental since the phenomena of industry require relatively complex methods for their analysis due to their complexity and the large number of data that normally is involved. In order to deal with the problems that arise in these areas, students and professionals in engineering fields need to be educated and trained beyond the skills that are part of the regular curricula, especially in the areas of production systems and operations management.

By identifying such desirable skills, universities and colleges have adapted their study programs and added a larger number of statistics courses. Thus, the study of industrial engineering includes courses such as design of experiments, statistical methods, statistical computation, etc. In these courses, students are expected to acquire in-depth theoretical insight and practical skills in order to be prepared for the challenges in the future professional field of industrial engineering. One of the central questions that needs to be examined is whether the inclusion of further statistics topics really prepares the students well for the challenges of the practice. Another fundamental question is how to strengthen the links with practice within the university mechanisms in order to create synergies to improve the statistical capacities of future industrial engineers?

In this paper, we describe a teaching initiative to bring the industry and its practices closer to the statistical education of future industrial engineers at the university. The initiative consisted of designing a statistics course for industrial engineers, in which guided visits are made to different industrial and manufacturing companies located in the city of Aguascalientes, Mexico. During these visits to the companies, real manufacturing and quality problems were first identified and later analyzed, and in some cases, practical solutions were provided by the students in the classroom as part of their assignment for the statistics course. To test the effectiveness of this teaching approach, a controlled experiment was carried out with control and experimental group in two Mexican universities: one public and the other one private; both located in the city of Aguascalientes. The main objective of the present study is to describe and evaluate an alternative educational setting that, unlike a traditional university course, is intended to better prepare students for the work in the industry. However, we also want highlight the need for connecting the practice and theoretical studies of industrial engineers. Such need comes from the fact that industrial engineering students tend to graduate from the university without a proper preparation for practice. This in turn could cause not only a bad reputation of statistics and its potential but even negatively affect students' dispositions and motivation towards the study and applications of statistics.

In what follows, we present a literature review on the statistical education of industrial engineers to situate our work in such a landscape. Then, we introduce some theoretical elements that give support to our teaching initiative. Finally, we describe the teaching approach and show the results of the controlled experiment.

2. BACKGROUND AND THEORETICAL FRAMEWORK

In this section, we present an overview of the literature that illustrates a gap between theory and practice that is part of the education of prospective industrial engineers. In particular, some proposals that have been made to reduce this gap are reviewed. Also, the model of statistical thinking of Wild & Pfannkuch (1999) is presented succinctly, which serves as a framework for our teaching approach.

2.1 THE NEED FOR PREPARING THE STUDENTS FOR THE PRACTICE

There is a consensus that the knowledge acquired by industrial engineers during their undergraduate education should be updated and adapted to the changing conditions of practice (Palma, de los Ríos & Guerrero, 2012; Mendoza-Chacón, Ramírez-Bolaños, Floréz-Obceno, & Diáz-Castro, 2016). However, the universities have not always reformed the content and style of education. Indeed, gaps have been identified in the statistical skills needed by industrial engineers, and there is a call to promote a better understanding of the application of statistical techniques before the students enter the labor market (Antony, 2003; Antony & Kaye, 2000). These gaps in students' knowledge and skills are often attributed to the lack of connection between theory and practice during the education process of future engineers and to the low orientation of the education towards engineering problem solving (Aamer, Greene, & Toney, 2017; Antony & Kaye, 2000). In order to fill these gaps and to link theory with practice, various approaches have been proposed.

Some approaches are based on the use of digital technologies, which favor the method of simulation and modeling of industrial processes. An example of this is the work by Miller & Bures (2015) who designed an industrial engineering course in which modeling software and e-books are used. In particular, the modeling software allows students to design and simulate production models of fictitious companies. Other examples of the use of modeling and simulation in industrial engineering – including stochastic modeling – can be found in Ram & Davim (2018).

Another approach is to let students work in teams on projects from statistical consulting work successfully completed at the department; the idea is to simulate real practice as authentic as possible (see, e.g., Borovcnik, 2018). Some arguments behind this proposal are that textbook examples are useful to show the routine but fail to meet basic requirements of applied statistics (modeling), and that artificial case studies might hide the complexity of applications.

Some authors propose to develop the statistical reasoning of industrial-engineering students through experiential learning (Fardillah, Sutaagra, Supriani, Farnila, & Priatna, 2019). This means that students learn from active experimentation and concrete experiences, to get engaged in a reflective observation that produces an abstract conceptualization. However, the "active experimentation and concrete experiences" do not always come from genuine situations provided by the industry – for instance, they could come from software-based simulations.

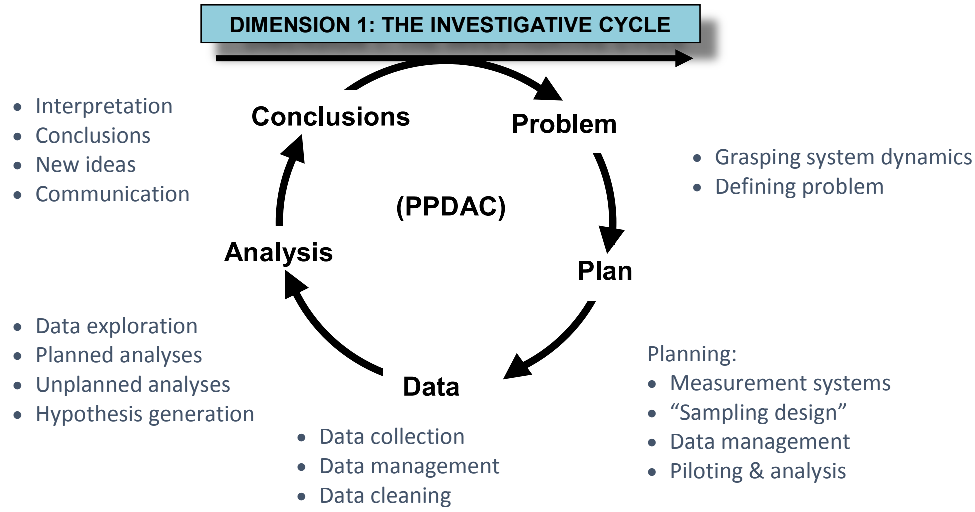
Still others propose to intensify the interaction and cooperation with industry. For example, McKinnis et al. (2001) point out that students benefit from the implementation of industrial outreach programs that provide them with relevant project experience and give them access to industrial facilities, so that they are much better prepared for their future employment. In addition, they state that the faculty itself benefits from such industrial programs by updating its practical skills and by solving important industrial problems.

In this paper, we examine the outcome of a teaching experiment, which is situated in the category of initiatives that attempt to bring actual industrial practices and problems closer to the university education of future industrial engineers. This teaching approach aims to promote the development of statistical thinking in students based on genuine industrial problem solving.

2.2 THEORETICAL FRAMEWORK

In this section, we present a theoretical framework that helps us to specify the type of components of statistical thinking that should be developed during higher education to make the students fitter for practice. One of the first and most relevant documents produced with the aim of analyzing the complex problem of studying and analyzing statistical problems is Wild and Pfannkuch (1999). The underlying model is called "Statistical Thinking in Empirical Inquiry". Figure 1 presents the so-called four-dimensional framework for statistical thinking in empirical research. There are several dimensions of this model that can be analyzed in educational research.

Figure 1. A four-dimensional framework for statistical thinking in empirical enquiry



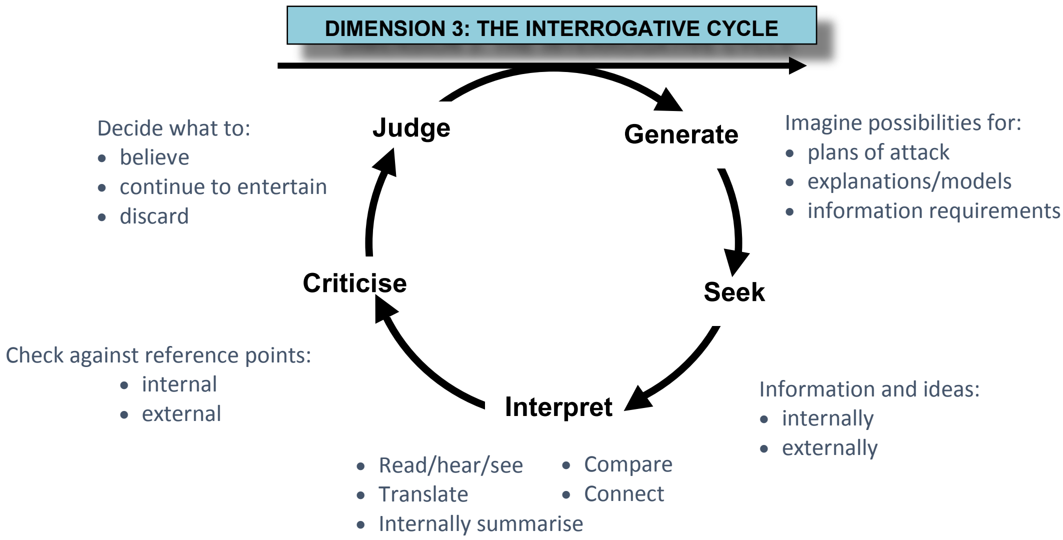
DIMENSION 2: TYPES OF THINKING

GENERAL TYPES OF THINKING

- **Strategic**
  - planning, anticipating problems
  - awareness of practical constraints
- **Seeking Explanations**
- **Modeling**
  - construction followed by use
- **Applying Techniques**
  - following precedents
  - recognition and use of archetypes
  - use of problem solving tools

TYPES FUNDAMENTAL TO *STATISTICAL* THINKING (Foundations)

- **Recognition of need for data**
- **Transnumeration**-Changing representations to engender understanding
  - capturing "measures" from real system
  - changing data representations
  - communicating messages in data
- **Consideration of variation**
  - noticing and acknowledging
  - measuring and modelling for the purposes of prediction, explanation, or control
  - explaining and dealing with investigative strategies
- **Reasoning with statistical models**
- **Integrating the statistical and contextual**
  - information, knowledge, conceptions



DIMENSION 4: DISPOSITIONS

- **Scepticism**
- **Imagination**
- **Curiosity and awareness**
  - observant, noting
- **Openness**
  - to ideas that challenge preconceptions
- **A propensity to seek deeper meaning**
- **Being logical**
- **Engagement**
- **Perseverance**

Source: Wild & Pfannkuch (1999, p. 226)

- The first dimension, "the investigative cycle", refers to how we proceed during the development of a statistical investigation. It refers to how a statistical problem is abstracted from a real problem and solved.
- The second dimension called "types of thinking" makes reference to the general and specific types of thinking, which may emerge by engaging in a statistical problem-solving process.
- The third dimension, "the interrogative cycle", represents a generic thinking process that is put into play during a statistical problem-solving process.
- Finally, the fourth dimension, "dispositions", refers to generic personal qualities that could condition the development of a statistical investigation. It is important to note that such dispositions are problem dependent: "they change according to the degree to which the person is engaged by the problem" (Wild & Pfannkuch, 1999, p. 235).

To narrow the study, we focus on Dimensions 3 and 4, i.e., the interrogative cycle and the dispositions of the students. The reason for this was that we were interested in investigating whether the direct interaction with problem solving within industrial organizations has an impact on the way students develop statistical skills and how such a link could help to promote a better disposition towards statistical studies. Although the first dimension, the investigative cycle, could be present in problem-solving situations, we decided not to consider it because in the teaching experience that we implemented the students did not experience all the phases of this cycle (for instance, they did not collect the data by themselves).

3. THE DIDACTICAL EXPERIMENT

In this section, we provide more details about the implementation of our teaching experiment. In particular, we give a general description of the students who participated in the study and of the course, in which this didactic experiment was embedded. We also provide more details of the didactic interventions in the experimental and the control groups.

3.1 DESCRIPTION OF THE STUDENTS AND THE COURSE

One of the authors of this paper had the opportunity to offer the course *Quality Engineering* in the academic years 2014–16 at two universities, a private and a public one. The study programs are basically equivalent; the core curriculum focuses on sampling techniques and the use of traditional control charts: X-bar, R, c, and u (Lohr, 2010; Montgomery, 2013). The main characteristics of the students in both groups are shown in Table 1.

Table 1. General characteristics of students

Group	*Year*	*Type*	*University*	*Number of Students*	*Average age (years)*
1	2015	Experimental	Private	30	20.1
2	2015	Control	Public	29	19.9
3	2016	Experimental	Public	31	19.8
4	2016	Control	Private	27	20.0

As can be seen from Table 1, the four groups that participated in the study are quite similar, both in the number of students attending the courses, and in their average age (in fact, the course of "Quality Engineering" is offered in the fifth semester of studies in the two educational institutions, so that such coincidences are not surprising). We pooled the groups and had an experimental group with 61 and a control group with 56 students (see below).

The purpose of such courses is to teach theoretical elements and, as a practical matter, to apply classical sampling schemes (simple random sampling, cluster sampling, stratified sampling), and control charts. Due to the nature of the subject, the teacher decided to use hybrid teaching techniques through project-based learning, using the methodology developed in Kargar, Tarmizi, & Bayat (2010), Bland (2004), and OCR (2014) (a complementary source is Marriott, Davies, & Gibson, 2009).

3.2 THE DIDACTIC INTERVENTION IN THE CONTROL GROUP

Now, we describe the intervention implemented in both groups. All the material given to the students in the control group was applied only in the classroom, i.e., all theoretical and practical aspects of the course were addressed within the classroom. All the requirements were clearly pointed out from the beginning of the course. For instance, the students were required to gather information from the Internet, books, or from research papers to develop their projects. The data then was prepared for analysis and finally analyzed by those statistical techniques that were learned in the course. On a weekly basis, the students had to send to the teacher the respective progress with the technical results for their project. The project consisted of the following elements:

a) A clear statement of the context, in which the problem emerges. That is, to mention the organization's name, industry or factory from where the data was derived, as well as some other details about the underlying processes.
b) Description of the main findings in terms of the organizational structure, organization chart, number of employees, and the financial data; in particular, the cost of operation and profits before and after taxes.
c) Incorporation of theoretical elements underlying each statistical technique that was studied during each week of the course.
d) Adherence to the implementation of such techniques as well as their results, within a particular process of production in the organization.
e) Generation of recommendations to the organization in relation to each of the statistical techniques in order to increase their competitiveness and efficiency.
f) Formation of a corpus of reflections, conclusions, and general comments at the end of the project.
g) Finally, the sources of information used for developing the project.

3.3 THE DIDACTIC INTERVENTION IN THE EXPERIMENTAL GROUP

Both universities involved in this study are institutionally linked to the industry. This means that for at least 20 years in the public and 12 years in the private university, there has been a continuous interaction between academia and industry in different ways, such as sponsorships, graduation practices, and in our case, carrying out student visits. This institutional commitment is relevant to achieve an efficient and convenient relationship for both stakeholders.

We organized five scheduled visits during the semester, during days that were agreed by the university's liaison office, the teacher, and the company staff. This model was not arbitrary; rather it was based on an analysis by the teacher in order to achieve a balance between the aim of having enough time to carry out the teaching material, and not overburdening the company.

An important aspect of the design is that the teacher required that the company's chief engineer be the one conducting the introduction, development, and conclusion of the sessions. This was due to previous experiences where the sessions were conducted by low-level operators, leading to unpleasant events such as an incomplete picture of the sub-processes within the general production cycle. In order to guarantee such visits, the teacher contacted the chief engineer personally, and explained him this request. Fortunately, in all cases the visits were conducted as requested (part of the reason for choosing five sessions was to keep the interruptions to the chief engineer's work at a reasonable level). The following aspects were essential for the meetings:

- In all cases, the guided visits began between 8:00 and 9:00 a.m. and the introduction, the development, and the conclusion lasted approximately 60 to 90 minutes.
- Another essential aspect was the fact that the chief engineer was asked to provide the data to be statistically analyzed by the students. On the basis of reciprocity, students were asked to submit a proposal to the chief engineer to improve the manufacturing process, which was accompanied with an analysis of the main results and recommendations. To this end, a subgroup of students, representative of the entire class and appointed by the teacher, had the responsibility of collecting such results in order to organize them and clearly present them to the chief engineer.
- The introduction, which was carried out by the chief engineer, started with a general welcome, an explanation of the most important organizational features of the company (such as a short company history, the current owners, and the main processes and products manufactured in the factory). This stage was sometimes accompanied by a short video in which such elements were illustrated.
- During the development of the sessions, the whole class was asked to attend one of the production sites where the production process was explained in detail, i.e., what are the inputs, what are the production processes involved, what knowledge, skills, and abilities the operators should have, what is the final product generated through the process, whether there are intermediate processes before generating the final product, and what are possible sources of interference that could delay or interfere with the production process.
- At the end of the sessions, the students returned to the first meeting point where a formal dismissal by the chief engineer took place, and then the students came back to their university. During all visits, the students and the teacher had the institutional support so that they could travel in the company's official vehicles.

Depending on the data provided by the company, the students in the experimental group had to use various sampling techniques or control charts to generate the corresponding results. Progress should be reported to the teacher on a weekly basis, in the same way as the students did in the control group. Taking as a reference two or three of the best developed analyses, from the teacher's point of view, the groups' representatives of the whole class should hand in a report containing these analyses to the chief engineer during their next visit.

4. EMPIRICAL EVIDENCE

In this section, we present the instruments used to evaluate the development of students' statistical thinking. We describe the problems and open questions that were presented to the students at the end of the Quality Engineering course. We present a quantitative analysis of their performance in statistical problems and a qualitative synthesis of their answers to the open questions.

4.1 THE EVALUATION INSTRUMENT

A week prior to the completion of the Quality Engineering course, the projects developed by all the students were collected. Additionally, a written examination was applied to all students. The written examination was composed of three problems (problems 1 to 3) related to sampling schemes, which were taken from Lohr (2010). The examination also included two other problems (problems 4 and 5) taken from the text of Montgomery (2013):

1. Simple random sampling (Problem 1, Section 2.12).
2. Stratified sampling (Problem 2, Section 3.9).
3. Sampling by conglomerates with equal probabilities (Problem 1, Section 5.8).
4. X-bar and R charts (Problem 6.3, p. 280).
5. Nonconformities chart (Problem 7.5, p. 344).

As an illustration, we present Problem 4 taken from Montgomery (2013, p. 280). The rest of the problems are included in the appendix.

4. A manufacturer of components for automobile transmissions wants to use control charts to monitor a process producing a shaft. The resulting data from 20 samples of 4 shaft diameters that have been measured are:

$$\sum_{i=1}^{20} \bar{x}_i = 10.275, \sum_{i=1}^{20} \bar{R}_i = 1.012$$

Suppose that several of the preliminary 20 samples plot out of control on the R chart. Does this have any impact on the reliability of the control limits of the chart?

To investigate the Dimensions 3 and 4 of Wild and Pfannkuch's model (1999), the students were asked the following open questions in connection with the problem previously presented:

1. Explain how you arrived at your conclusions.
2. Generate a set of strategies that could help to improve the conditions displayed.
3. How can you transfer the results that you have found in your statistical analysis to the top management of the company, assuming that they are people who generally have no statistical knowledge (or have probably forgotten such knowledge)?
4. Do you think that the analyzed data could be real, i.e., could it come from an actual company? Argue your answer.
5. In what way could you extract more information to generate conclusions that bring more value to the top management of the company?
6. Do you think it is enough to maintain the logical consistency of your statistical analysis, or should you develop support strategies to strengthen your analysis?

4.2 ANALYSIS OF THE RESULTS

In a first examination, we found no difference between the students of the private and the public university, so we could put them together. For the differences between the control and experimental groups, we graded the performance on each problem on a scale of 0 to 10. Table 2 provides the mean performance of both groups and 95% confidence intervals for the difference and for the ratio of the variance between both groups.

Table 2. General performance of the students

Prob-lem	*Mean*			*95% confidence intervals*	
	Experimental E	*Control C*	*Mean E – Mean C*	*Mean E – Mean C*	*Ratio Var E / Var C*
1	8.99	7.04	1.95	1.32 – 2.57	0.32 – 0.71
2	8.69	7.13	1.56	0.71 – 2.41	0.23 – 0.73
3	9.23	8.77	0.46	0.05 – 0.87	0.27 – 0.85
4	8.74	7.51	1.23	–0.12 – 2.57	0.88 – 1.30
5	9.12	8.40	0.72	0.45 – 0.99	0.11 – 0.65

From this table, we can observe that in problems 1, 2, 3 and 5, the experimental students who interacted with industrial processes have a significantly higher performance than the control group: about 1–2 points for Problems 1, 2, and 4 (although this difference is not significant at the 5% level, because of the higher variance of the performance in Problem 4), and 0.5–0.7 points for Problems 3 and 5. Because it was also of interest, the 95% confidence intervals of the quotient of the variances of the two groups were also calculated to analyze the homogeneity or heterogeneity of the performance of each question. As can be seen, only in the fourth item it could be concluded that the two variances are the same, and in all other problems the variance is significantly smaller in the experimental group; except for Problem 4 where the experimental group has a greater compactness in the answers than the students in the control group. Moreover, the confidence intervals between means show that in Problems 1, 2, 3, and 5, the performance of the experimental group seems to be better when comparing it with the control group's performance, this is because 0 is not contained in such intervals and, in fact, the variances of the two groups seem to be different.

When analyzing the answers to the open Questions 1–6 provided by the students, it is possible to perceive a difference between the control and experimental groups. The differences lie in their identification of the context, their criticisms, the generation of improvement strategies, among other aspects pointed out by the students when answering these questions. In what follows, we present a qualitative synthesis of students' answers to each of these questions.

Question 1. The experimental students explained that the conclusions that they obtained were linked to the characteristics of the production process that they experienced, while the students in the control group indicated that their conclusions were determined by a simulation process or by data that does not necessarily have a connection with real-life scenarios.

Question 2. Nearly all experimental students developed strategies aimed at specific actions within the processes involved in the context of the problem. That is, they identified concrete suggestions for the improvement of the training processes of the staff, and for the calibration of the machines. The students of the control group did not comment on this; in particular, there was a high non-response rate to this question, and those who answered used very general descriptions, such as generating SWOTs (Strengths, Weaknesses, Opportunities, and Threats) or vague recommendations to improve the data collection processes. The fact that the students in the experimental group made more varied proposals to improve different aspects of the process – including the training of the people who participate in it – could be interpreted as a manifestation of a greater sensitivity and awareness of productive processes and the contexts, in which they are relevant compared to the students in the control group.

Question 3. In this question, the majority of students in the experimental group indicated whether the process was under statistical control or not, and pointed out that in the case of a negative sample, it should be considered the possibility of analyzing a new sample, and carefully observe potential factors that could get out of control. In this question, the students in the control group answered in a very similar way.

Question 4. Both in the experimental and control group, the students answered that the data could be real. This argument was expressed in the sense that there are production processes that can produce this type of data and due to the erratic manifestation of the data, such behavior – as presented in Problem 4 – could actually occur. As we have just described, the answers to Questions 3 and 4 do not suggest any difference between the students in the experimental and in the control group.

Question 5. The answers to Questions 5 and 6 showed notable differences between the two groups of students. In the experimental group, the students repeatedly noted that, although a statistical analysis can be valuable, administrative considerations and the organization within the different projects may have a priority in the diagnosis, which is where the main opportunities for improvement could be located. In other words, even though the problem is statistical in nature, it is essential to establish a good communication between the statistical specialists (in this case, the students) and the agents in the productive processes in order to improve the whole production process. The control students made no proposals to extract more information beyond the one obtained directly by applying statistical techniques.

Question 6. In the experimental group, constant efforts were made to connect the facts obtained from the application of statistics techniques with the different administrative processes, and even other statistical or mathematical techniques. For example, the application of descriptive statistics (univariate and multivariate) to the data collected was often mentioned by the students. The application of a SWOT analysis to the different productive processes and the embedding of the issues in the general context of the organization, were also pointed out by the students. In the case of the students in the control group, no major contributions were provided here, aside from some exceptional cases where confidence intervals were considered for the mean and variance of the data under consideration.

We could argue two things here. On the one hand, Wild & Pfannkuch's model for statistical thinking points out that the interrogative cycle is a generic thinking process in constant use in statistical problem solving. Thus, since the students in the experimental group had the opportunity to make visits to actual industrial settings, in which they interacted not only with the data provided by the company but with some of the people in charge of the productive processes. This provided them with greater opportunities to immerse themselves in genuine statistical problem-solving processes, in which the interrogative cycle could be stimulated.

On the other hand, some of the students' answers to the open questions (particularly the answers to Questions 2, 5, and 6) suggest that students in the experimental group possess a more developed sensitivity to aspects of the production process – such as human and administrative factors – that the students in the control group tended to ignore. This in turn could be interpreted as a difference in students' *dispositions*.

5. CONCLUSIONS AND REFLECTIONS

The direct involvement of industrial engineering students in the observed production processes is proving to be a way of improving aspects of their statistical thinking. The results of our analysis show that on average, a mean gain of nearly 2 points on a ten-point scale is observed. Not only that, but also the greater compactness of the acquired knowledge can be seen as an improvement.

In other words, the mere situation of offering "practical" material only in a school context may be important for students but it is not sufficient to develop the necessary skills, understanding, and dispositions for the learned methods, which are so important for their future profession. Being in contact with the productive and analytical work of the industrial organizations seems to enhance students' skills not only in the reflexive, interpretative, and critical part of the dimensions of the interrogative cycle but also their dispositions.

It should be noted, however, that there are several aspects that need to be in place in order to implement this kind of industry-university cooperation approach. In order for the students to benefit from this, the following points should be considered: It is essential to plan the educational intervention in the industrial organizations properly; that means, it is necessary to avoid focusing on aspects of the production processes that are too general, or on aspects that are very specific to the organizational context.

In connection to this, a key issue is to count with a chief engineer who is an expert in the industrial processes at stake, and that possess the ability to clearly describe the specific aspects of such processes. But it is also necessary that such a person has the sensitivity to explain the material to the students in a way that they are able and willing to follow it.

Part of the teacher's responsibility is to help students to differentiate between the general and the specific aspects of the processes, but also to try to design a course that is challenging, interesting, and attractive for the students. The practical phase of this teaching approach should not become so overwhelming that it grows into an unmanageable burden for the students

Another aspect that is very important for the success of such cooperation with industry is the administrative link that must be maintained between the educational institution and the industrial organization. Once the communication between the two entities is established, it is crucial to identify what are the responsibilities, obligations, rights, and mutual benefits for both parties. In connection to this, it is also essential that the teacher is given enough flexibility to make decisions on how much information to provide to the students so that they find the assignments challenging but doable.

Within this line of educational research, there are some paths that would be worth exploring in future studies. For example, if the conditions to witness the productive processes in situ are not available to the students, how efficient would it be communicating such experiences through videos (plans, maps, etc.) that are pre-recorded or transmitted in real time from a distance? How relevant is the physical interaction of the student with the productive processes and the chief engineer, compared to a virtual interaction? Another topic for further study is whether it is worth investing time and efforts in the physical interaction with industry if the course is already challenging in terms of its theoretical content.

Based on our experience, we can say that the interaction between academia and practice is very positive. The benefit lies in the deepening of theoretical knowledge, the embedding of this knowledge in the broader industrial context, and also in the modification and improvement of the dispositions of the students towards the theory and the applications of statistics. The industry contacts can also have an impact on the self-esteem of the students. Such industrial add-ons to the courses also make it easier for students to work on demanding courses in statistics later on. With a reasonable amount of time and refined planning, the implementation of industry visits as a common practice in certain engineering programs can better prepare the students for their future and increase their career opportunities. Such interactions should take place as early as possible in their undergraduate education.

We are convinced that the teaching experience we have described in this paper has the potential to develop aspects of statistical thinking in industrial-engineering students, in ways that a course anchored in the classroom and based on the use of textbooks could not achieve. We hope that our experiment motivates other engineering institutions and – beyond that – teachers in the general statistical education to promote a closer relationship with the productive sectors and companies since they can provide us with invaluable opportunities to experience genuine and contextualized statistical problems. We are aware that these kinds of experiences require great will and effort from all the stakeholders involved but we think that the benefits for building the future generation of statisticians would worth the effort.

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APPENDIX:
FIVE STATISTICAL PROBLEMS FROM THE EVALUATION INSTRUMENT

The following are the problems taken from Lohr (2010) and Montgomery (2013) that constitute the evaluation instrument:

1. Let $N = 6$ and $n = 3$. For purposes of studying sampling distributions, assume that all population values are known.

$$y_1 = 98 \qquad y_2 = 102 \qquad y_3 = 154$$
$$y_4 = 133 \qquad y_5 = 190 \qquad y_6 = 175$$

We are interested in $\bar{y}_U$, the population mean. Two sampling plans are proposed.

Plan 1. Eight possible samples may be chosen.

Sample number	Sample S	P(S)
1	{1,3,5}	1/8
2	{1,3,6}	1/8
3	{1,4,5}	1/8
4	{1,4,6}	1/8
5	{2,3,5}	1/8
6	{2,3,6}	1/8
7	{2,4,5}	1/8
8	{2,4,6}	1/8

Plan 2. Three possible samples may be chosen.

Sample number	Sample S	P(S)
1	{1,4,6}	44044
2	{2,3,6}	
3	{1,3,5}	

(a) What is the value for $\bar{y}_U$?
(b) Let $\bar{y}_U$ the mean of the sample values. For each sampling plan, find
(c) i) $E[\bar{y}]$ ii) $V[\bar{y}]$ iii) $Bias[\bar{y}]$ iv) $MSE[\bar{y}]$
(d) Which sampling plan do you think is better? Why?

2. Consider the hypothetical population (this population is also used in Example 2.2). Consider the stratification below, with $N_1 = N_2 = 4$. The population is:

Unit number	Stratum	y
1	1	1
2	1	2
3	1	4
8	1	8
4	2	4
5	2	7
6	2	7
7	2	7

Consider the stratified sampling design in which $n_1 = n_2 = 2$

(a) Write out all possible SRSs of size 2 from stratum 1 and find the probability of each sample. Do the same for stratum 2.

(b) Using your work in (a), find the sampling distribution of $\hat{t}_{str}$.
(c) Find the mean and variance of the sampling distribution of $\hat{t}_{str}$. How do these compare to the mean and variance in Example 2.2?

3. A city council of a small city wants to know the proportion of eligible voters that oppose having an incinerator of Phoenix garbage opened just outside of the city limits. They randomly select 100 residential numbers from the city's telephone book that contains 3,000 such numbers. Each selected residence is then called and asked for (a) the total number of eligible voters and (b) the number of voters opposed to the incinerator. A total of 157 voters were surveyed; of these, 23 refused to answer the question. Of the remaining 134 voters, 112 opposed the incinerator, so the council estimates the proportion by

$$\hat{p} = \frac{112}{134} = 0.83582$$

with

$$\hat{V}(\hat{p}) = \frac{0.83582(1 - 0.83582)}{134} = 0.00102$$

Are these estimates valid? Why, or why not?

4. A manufacturer of components for automobile transmissions wants to use control charts to monitor a process producing a shaft. The resulting data from 20 samples of 4 shaft diameters that have been measured are:

$$\sum_{i=1}^{20} \bar{x}_i = 10.275, \sum_{i=1}^{20} \bar{R}_i = 1.012$$

Suppose that several of the preliminary 20 samples plot out of control on the R chart. Does this have any impact on the reliability of the control limits on the chart? (Montgomery, 2013, p. 280)

5. The commercial loan operation of a financial institution has a standard for processing new loan applications in 24 hours. Table 7E.2 shows the number of applications processed each day for the last 20 days and the number of applications that required more than 24 hours to complete.

Table 7E.2 Loan Application Data for Exercise 5

Day	*Number of Applications*	*Number Late*	*Day*	*Number of Applications*	*Number Late*
1	200	3	11	219	0
2	250	4	12	238	10
3	240	2	13	250	4
4	300	5	14	302	6
5	200	2	15	219	20
6	250	4	16	246	3
7	246	3	17	251	6
8	258	5	18	273	7
9	275	2	19	245	3
10	274	1	20	260	1

(a) Set up the fraction nonconforming control chart for this process. Use the variable-width control limit approach. Plot the preliminary data in Table 7E.2 on the chart. Is the process in statistical control?
(b) Assume that assignable causes can be found for any out-of-control points on this chart. What center line should be used for process monitoring in the next period, and how should the control limits be calculated?