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Testing a QFD Methodology to Improve a Calculus Course for Engineers*

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The aim of this work is to advance the teaching quality of a first-year Calculus course through the use of a cycle of continual improvement. This requires the use of a tool that both helps to gather information on the quality achieved and to detect areas in need of improvement. The Quality Function Deployment (QFD) matrix can be used as such a tool. However, following the reviewed literature, the way in which the QFD is employed is indeed variable, and it has rarely been used for a first-year subject. We have developed and implemented a methodology based on the use of QFD matrices focused on student opinions. Our method is easily implementable by professors, and it does not require specific training, nor does it involve high costs. By means of a survey, we have collected the perceptions of the teaching quality, or lack thereof. These results have been analyzed through House of Quality (HoQ) diagrams to place a value on the specifications of the course and to identify and target those characteristics of greater importance, with the end goal being to improve quality. From this analysis, we have extracted some guidelines for improvements to be implemented. The study has been made in two consecutive years. The comparison of the two years shows that the weaknesses identified in the first year, and the improvements introduced for the second year, have created a significant increase in perceived quality. This methodological approach is useful in that it allows an evaluation of teaching quality. It helps in the determination of possible avenues for improvement, and ultimately it allows for an analysis of the evolution of perceived quality over time.

Keywords: first-year engineering; calculus; QFD; quality improvement

1. Introduction

In order to be competitive, one must realize the importance of "quality." Given this general statement, "quality" shall be further defined as follows: the ability to adjust a product or service in accordance with the needs and expectations of a customer [1]. Akao et al. [2] consider three main groups of customers of University teaching: the first one is formed by teachers, students and University's management staff, the second is potential future students and the last is the businesses that provide the prospect of employment opportunities for future graduates. Each of these groups can be considered to be a customer, although each in a distinct capacity, of the teaching services provided by the University [3]. As such, Pitman et al. [4], and Duffuaa et al. [5] consider the students and businesses to be equal. On the other hand, some authors believe that it is inappropriate to consider students as "customers," given that they are an active part of the education process itself and of the University's functioning [6, 7, 8].

On the other hand, Rizwan et al. [9] consider the student to be the primary stakeholder in the University's education system. Mazur [10] claims that the focus of the external evaluator (mainly the future employer) should be mainly concerned with taking note of the contents and objectives of the coursework, while the internal client (mainly the student) ought to be more concerned with the format and design of the material. However, Periáñez [3] notes that the opinions of the students are key in that their level of satisfaction with the coursework cannot help but influence the results, even if it were only for the influence of this satisfaction in the motivation and the work environment in classrooms. Finally, Stedinger [11] underlines the importance of familiarizing oneself with the expectations of the students while noting that, beyond the basic principles of Quality Management, in the case of teaching one must also keep in mind a fourth idea: "Learning requires student effort."

There are techniques that allow the establishment of a relationship between customer expectations ("customer voice") and the characteristics of the product or service provided. The QFD (Quality Function Deployment) is one of them [2]. With the help of QFD, the demands of the customer translate into modifications of the product that satisfy the expectations expressed in the QFD. This tool is part of a Deming cycle of continuous improvement (Plan, Do, Study, Act [12]) adapted to education (Plan, Implement, Evaluate, Improve: PIEI [13]).

The most common type of QFD employed is a matrix, typically referred to as the "House of Quality" (HoQ). In this matrix, the first column is dedicated to the "customer voice," broken down

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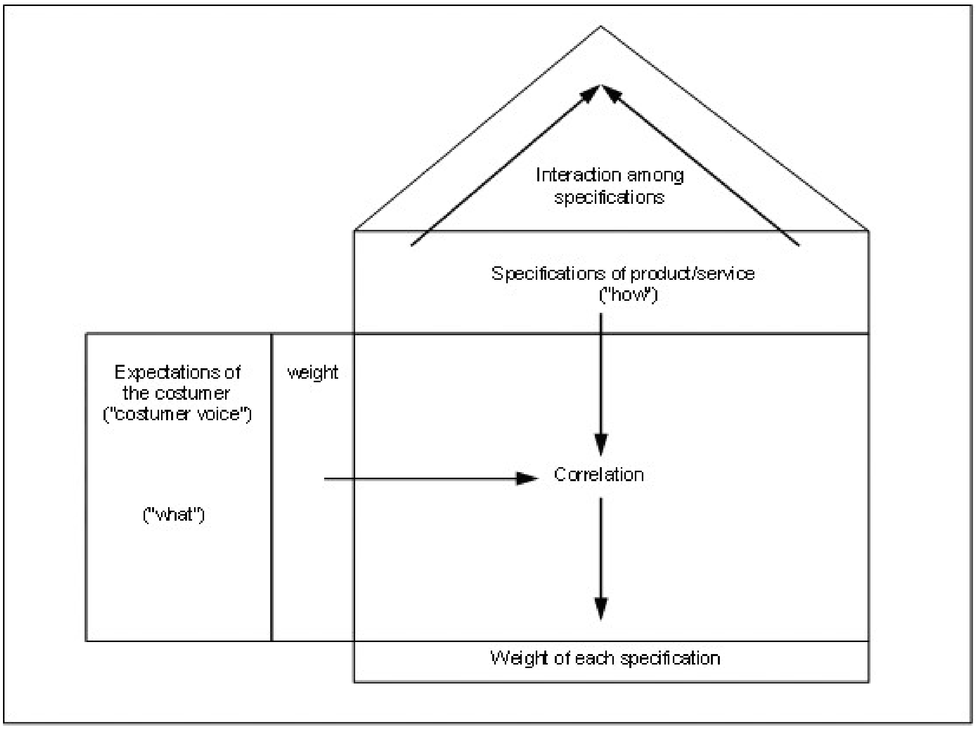

Fig. 1. QFD matrix or House of Quality (HoQ).

into a series of expectations to be met, while the row contains the specifications of the product (Fig. 1).

The QFD has been used over many recent years in Higher Education [10, 14] with great success in various capacities: the betterment of teaching institutions [15, 16], teaching practices [7, 17–19] and for the designing of courses [4, 5, 10, 19–24]. However, the methodology employed in those papers is not the same one, which means there is not a consensus on a common practice [24]. In the present work we have developed and tested a new methodology that collects contributions of the literature while simultaneously incorporating an easily implementable strategy that allows for easier use by professors without necessitating special training or sophisticated means.

Therefore, the objective of this study is the implementation of a methodology for the application of QFD as a tool for improving the quality of education, especially but not exclusively adapted to the subjects of the first engineering courses. This research presents an iterative process improvement, which allows for (1) the verification of the increase in the perceived quality as judged by the student (whether or not the modifications made to the coursework were actually satisfying the expectations of the student), and (2) the proposal of new ways to improve subsequent courses. This process has been developed for the Calculus I course within a Spanish school of engineering during the 2006–2007 and 2007–2008 school years.

2. Description of the course

Calculus I is taught in the first year of the programs of Industrial Engineering and Chemical Engineering. The class spans both of the first two semesters of the first year (3.5 hours per week). Each topic begins with a presentation of the possible applications of the material that is to be studied. Then, in a cyclical manner, various theoretical concepts are explained, followed by an example of their use. Finally, a problem set is used that, in a meaningful way, employs the discussed theories, concepts and principles of the material. The class is led by a professor and a graduate assistant.

Once a week, the class is devoted entirely to the solving of problems related to the previous week's presented concepts. Furthermore, each week three office hours are provided for those students who wish to seek additional help.

For the student's own personal study time, they have the available resources of a recommended bibliography and a collection of problem sets. Also, Blackboard™ is incorporated as a platform for the support of teaching.

3. Application of QFD

A QFD matrix was constructed in order to relate the expectations of the students with the specifications of the course. The steps for the creation of the QFD matrix were as follows [1].

1. Gauge the expectations of the customers through the use of a survey.
2. Classify said expectations according to their importance.
3. Identify the technical specifications of our service.
4. Relate expectations with specifications. Relate also specifications among them (QFD matrix).
5. Evaluate the specifications of the service and determine those that seem to carry more weight.
6. Determine the appropriate action to take in order to modify the specifications with the objective being the betterment of the perceived quality.

The QFD matrix was created for two consecutive years. The first of which was the academic year 2006–2007, and its purpose was to detect possible avenues for improvement. Such detections, and their subsequent advancements, were implemented in the second of the two-year study period, 2007–2008 and the resulting satisfaction ratings of the students were studied.

3.1 First iteration (2006–2007)

3.1.1 Procedure

In order to identify the expectations of the customers, a survey was administered to the students of the academic year 2006–2007. The results of this survey gave us the "customer voice." The survey consisted of four open-ended questions, which were designed to be completed by the students:

(a) The best feature of this Calculus course was . . .
(b) Things lacking in this Calculus course were . . .
(c) For me, the most important feature of a Calculus course is . . .
(d) Other comments:

The questions "A" and "B" gave direct feedback regarding the goals and the shortcomings of the course. The question "C" provided insight into the subjective importance as observed by individual students for various topics. And finally question "D" provided the students with a space to share more specific or private comments.

The survey was completed voluntarily and anonymously by 108 students at the end of the 2006–2007 academic year (May of 2007).

In order to gauge the results of the survey to determine actual customer expectations, the responses expressing similar ideas were grouped into *bins* as a first level of gathering like subjects; later, these *bins* were further aggregated into *categories* by grouping answers that concerned the same subject. This treatment of the responses was conducted separately for each of the four different questions on the survey.

The *bins* and *categories* were ordered by their respective frequencies with which they appeared in the surveys; i.e., the number of answers that belong to each bin and category. In this way, we obtained a relatively clear snapshot of the interests and concerns of the students organized by importance level, or priority. The resulting *categories* are shown in Table 1, with their respective frequencies.

In order to determine a specific plan for improvement, the Pareto Diagram (Figs 2 and 3) allowed us to easily select the *categories* with the highest frequencies. A Pareto Diagram is simply a Bar Chart in which the bars are sorted into size order, with the highest bar on the left, with addition of an accumulative line, beginning at the first bar from the left [1]. Five main *categories* were selected: *professors, problem-sets, teaching material, class methodology* and *consultations (*office hours*)*. These five *categories* represented 75% of the total responses from the survey questions A and B.

Next, the specifications of the service were firmly identified. These specifications are the characteristics of the course that can be modified in order to adapt the product to the expectations of the customers. To achieve this, the professor and his graduate assistant separately created a list of these specifications. Later, they combined their lists and agreed upon the following list of specification objectives for possible improvement:

Table 1. Categories and their respective frequencies for course 2006–07

Category	Question A	Question B	Question C	Question D	Total
Problems	34	40	17	0	91
Teaching material	32	45	9	2	88
Professors	43	4	37	1	85
Learning objectives	20	3	46	1	70
Office hours	25	32	7	1	65
Class methodology	30	22	9	2	63
Content	12	8	12	4	36
Student engagement	1	0	31	0	32
Evaluation	2	10	12	8	32
Invalid answers	7	13	6	5	31
Theory	12	9	7	0	28
University environment/conditions	6	5	2	0	13

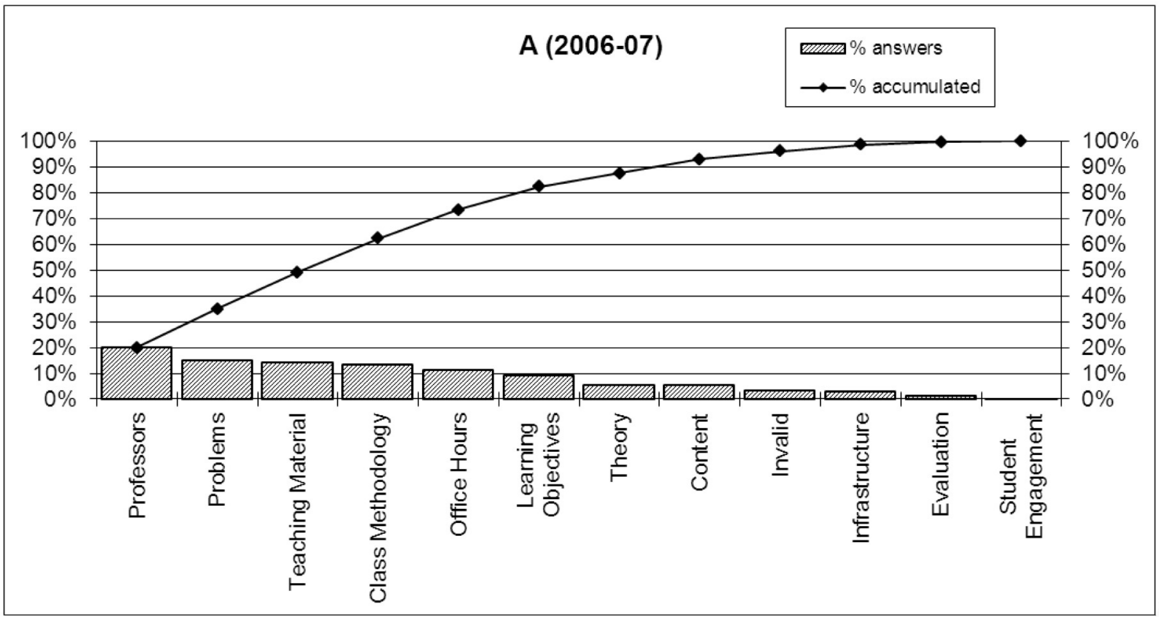

Fig. 2. Pareto diagram of the categories of question A.

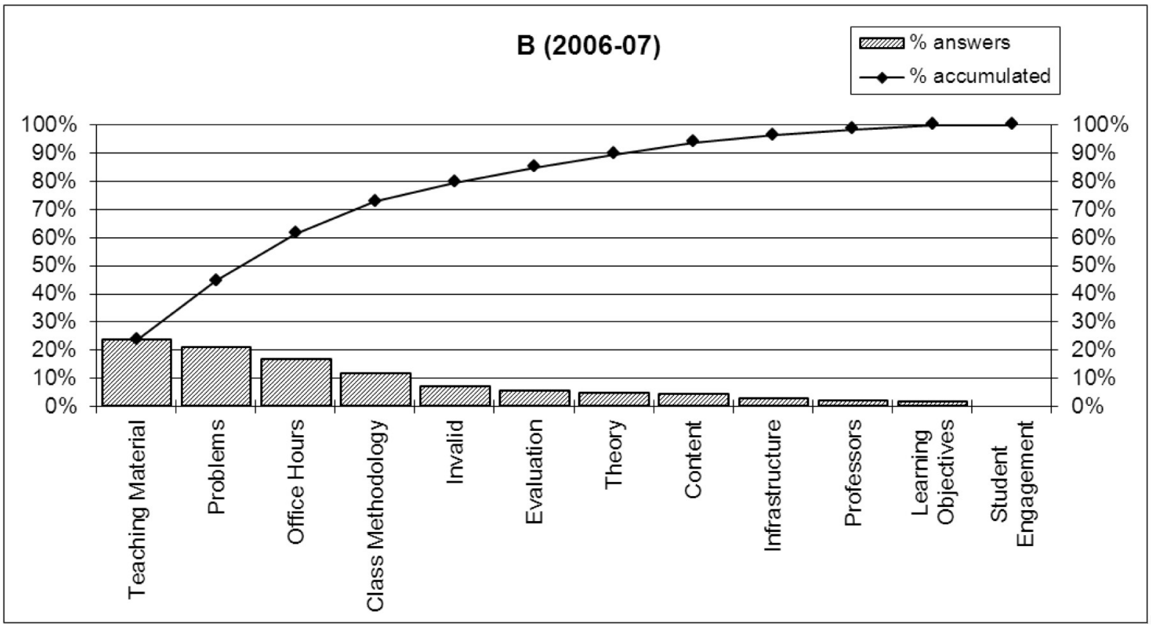

Fig. 3. Pareto diagram of the categories of question B.

1. Teaching Material
   1a. Collection of problems
   1b. Notes and other supportive material
   1c. Bibliography
2. Supportive Material for Class
   2a. PowerPoint
   2b. Calculus software
3. Time Distribution in Class
   3a. Proportion of theory/practice (proportion of class time devoted to theoretical explanations compared with practice exercise resolution)
   3b. Number of new concepts per session
   3c. Number of problems solved per session
   3d. Class time dedicated to individual student work-time
4. Class Dynamic
   4a. Number of examples (i.e. simple applications of any concept that has been introduced, in order to clarify its meaning or utility)
   4b. Number of practical applications (for instance, the calculus of inertia moments in order to illustrate an application of multiple integrals)

4c. Number of questions for the students (when the teacher asks a question related to the subject being treated, the class or individual students)
4d. Problems completed by students in class
5. Consultation (Office hours)
5a. Office Hours schedule, for consultations.
5b. Number of students attended to
5c. Seminars (a session devoted to the resolution of questions proposed by students)
6. Timing of Agenda
6a. Time allotment according to topic importance
7. Evaluation
7a. Exam with similar level of difficulty as problems completed throughout the class
7b. Supportive material for the exam (formulae, computer, tables)

Following this process, the professors created the QFD matrices in order to relate the "customer voice" resulting from the surveys with the specifications cited (Appendices I and II). The matrices allowed the calculation of the weight of each specification with respect to student satisfaction by adding, for each column of the matrix, the weight (measured by the frequency) of the "voice of customer" by the degree of correlation (0: no correlation, 1: weak correlation, 3: clear correlation, 9: strong correlation) with each specification (shown in the central cells of the matrix). For instance, in the Fig. 10, the column devoted to "exam with similar level or difficulty as problems completed throughout the class" has been found to have a strong relationship (9) with "collection of problem-sets (as a contents)", a clear relationship (3) with "collection of problem-sets (as a material delivered)", "problem solving sessions" and "abundance of exercise solved in class", a weak relationship (1) with "variety of assigned problems", and no significant relationship (0) with the other answers of the students. So, the weight of that specification is the sum of the product of the frequency (2nd column of HoQ) of every *bin* (1st column) by the relationship with this specification. In this example: $22 \times 3 + 6 \times 3 + 1 \times 9 + 20 \times 3 + 2 \times 1 = 155$. This value represents a measure of importance of this specification in students' satisfaction or perceived quality. The analogue value in Fig. 11 indicates the importance of this specification in students' dissatisfaction or perceived lack of quality. The result is presented in diagrams 4 and 5.

The Pareto diagram indicates the weighted importance of each of the specifications of the course for the satisfaction of the expectations of the students; it is calculated as a percentage for each column, with respect to the total.

The first outcome that we obtain from the study of the QFD matrices is that there are selected characteristics that exert a clearly dominant force over the others. For question "A" these characteristics are:

- Office hours
- Number of students attended to during individual consultation
- Proportion of theory/practice
- Number of problems solved per session
- Collection of problems
- Number of practical applications.

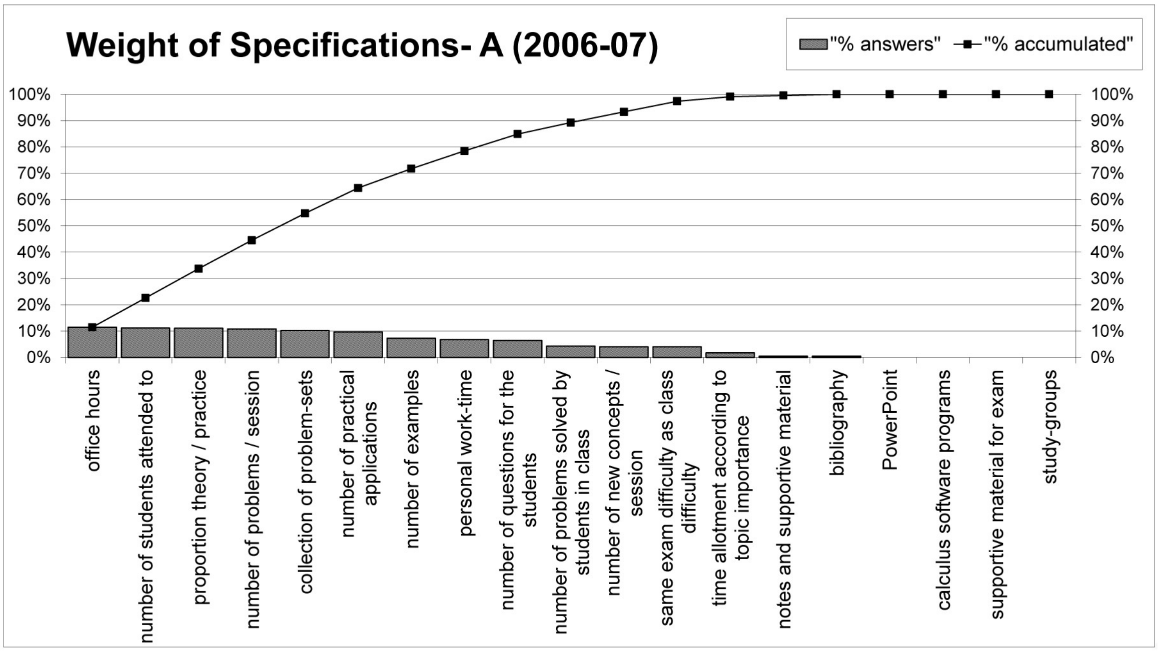

Fig. 4. Weight of specifications in the answers to the A question (achieved quality).

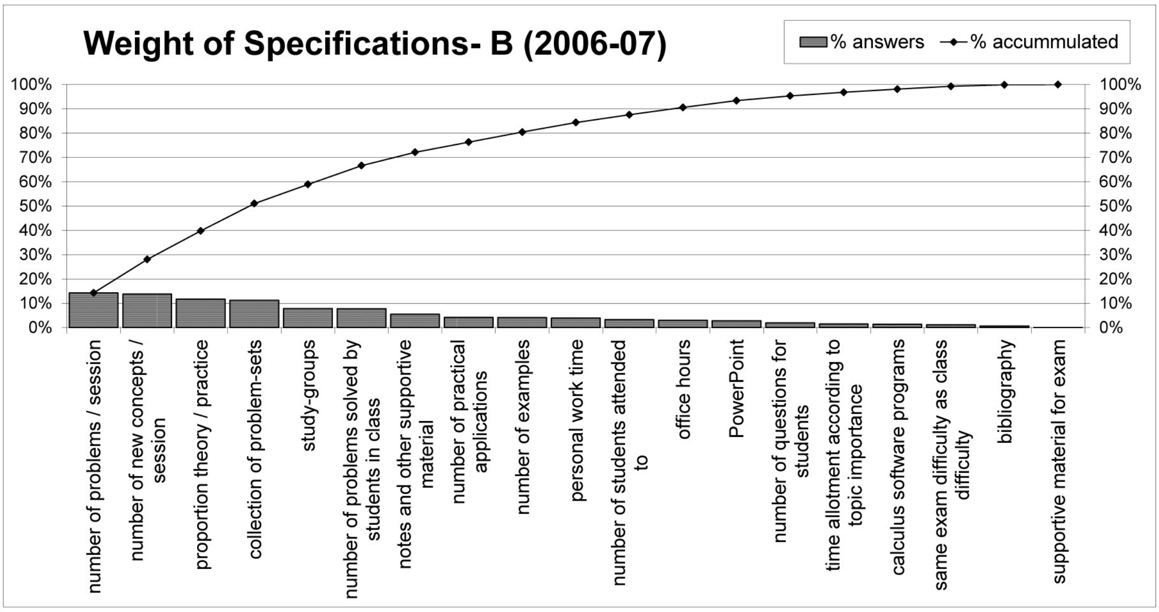

Fig. 5. Weight of the specifications in the answers to the B question (not achieved quality).

For question "B" the most significant categories were:

- Number of problems solved per session
- Number of new concepts per session
- Proportion of theory/practice
- Collection of problems
- Seminars
- Number of problems solved by students in class.

There are three categories that repeat themselves in the two questions:

- Proportion of theory/practice
- Number of problems solved per session
- Collection of problems.

One conclusion that could be drawn is that these three characteristics are very important for the satisfaction of student expectations, given that they greatly influence the satisfaction and dissatisfaction. Consequently, one must focus on the manner in which these characteristics can be maintained and improved.

Next, other significant characteristics appear:

- Number of new concepts per session
- Seminars
- Number of problems solved by students in class.

When making decisions to improve the courses, one must also keep in mind this group of characteristics.

Finally, other categories were shown to be simultaneously satisfactory and important. These are the main aspects to maintain and evaluate:

- Office hours
- Number of students attended to during individual consultation
- Number of practical applications.

This analysis is reflected in the graph of Fig. 6. This graph has been constructed from the information contained in the Pareto graphs (Figs. 4 and 5). They represented the main specifications, in a decreasing order of combined weights "A" + "B," and distinguishing the weights of "A" as positives (quality achieved), and the weights of "B" as negatives (quality not achieved). This gives us the combined weight and the compared weight of both questions, "A" and "B". The value of "A" + "B" informs us on the overall weight of a specification with reference to the perception of quality by the student. If the associated bar of a determined specification is quite long, that indicates that the said specification is very important to the satisfaction or dissatisfaction of the customer. A bar strongly shifted towards the right means that the corresponding specification is yielding a high level of satisfaction for the customer; on the other hand, a bar shifted very much to the left indicates that the corresponding specification is a source of strong dissatisfaction for the customer. Therefore, our interest is in shifting the longer bars (specifications) towards the right.

At first view of this diagram, we can see that first four characteristics stand out in overall weight and also in the fact that part "B" (not achieved) is large. Also, the importance of two other specifications must be stressed ("Number of problems solved by students in class" and "Seminars") in that the size of the portion "not achieved" is quite large.

Now it becomes necessary to study the interrelation between the various specifications of the product, which can be realized through the use of a half matrix that relates the list of characteristics among themselves, specifying its interrelation (positive or negative). The result is shown in Appendix III.

From these interrelation results, it is necessary to stress those that link the sections "Time Distribution in Class" and "Class Dynamic." These interrelations were strong, which is logical, in that the amount of time for each session is limited, the duration of each course is predetermined and the proportion of theory to practice is mutually exclusive.

3.1.2 Specifications and objects of improvement

Once the student expectations have been revealed, evaluated and correlated with the different specifications of the Calculus I course, we focus ourselves on the six specifications that were found to be most critical for the satisfaction of the "customer voice," and the most easily improvable:

(a) Number of problems solved per session
(b) Proportion of theory/practice
(c) Collection of problems
(d) Number of new concepts per session
(e) Number of problems solved by students in class
(f) Seminars.

After viewing these results, three of the six were chosen to be implemented in the 2007–2008 academic year.

1. Revise the theoretical content of the course in order to eliminate superfluous material.
2. Offer seminar sessions
3. Include the solutions to all problems.

3.2 Second iteration (2007–2008): Implementation of the improvement strategy

During the 2007–08 course, the planned improvements were implemented into the course and a second study using the same methodology was realized.

3.2.1 Procedure

The same survey was again passed out to the students. This time, 76 students responded voluntarily. The results were treated in the exact same manner and using the same methodology as with the first iteration. The result of the second grouping is shown in Table 2.

The most significant factors for the students on question "A" (satisfactory aspects), have concentrated slightly, resulting in a lesser number of *categories*. In contrast, the dominant topics are the same for both the first and second iterations of the survey: *problem-sets, teaching material (collection of problems), professors, and class methodology*. The

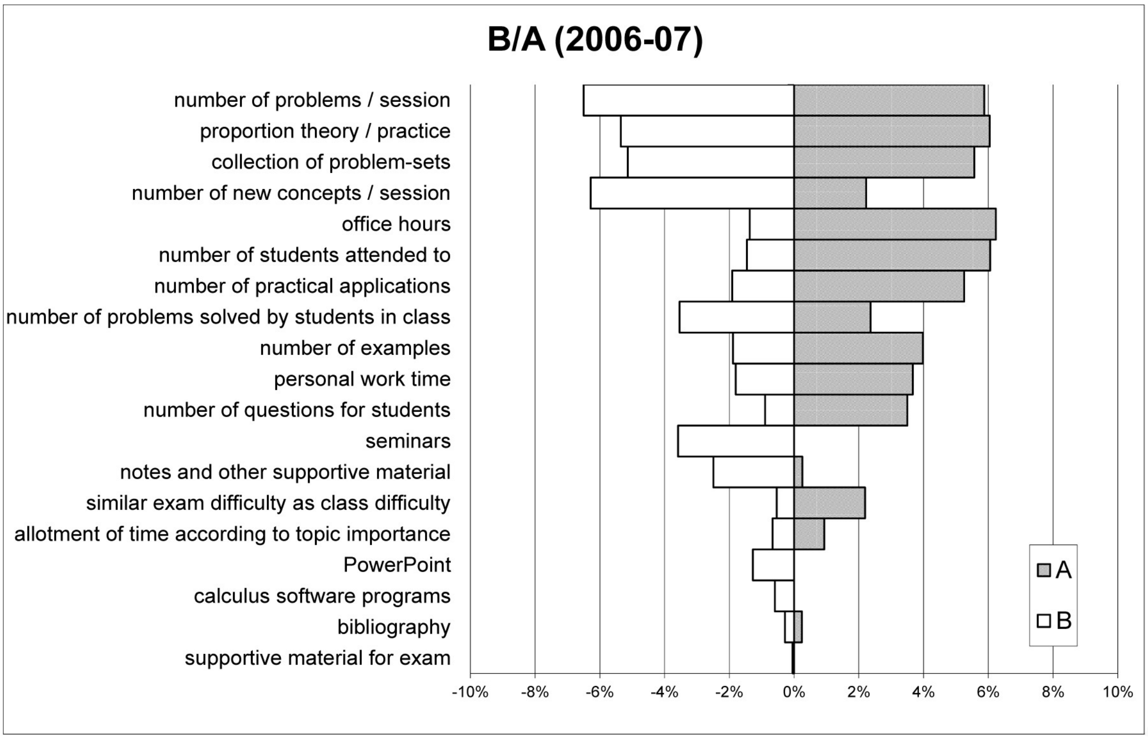

Fig. 6. Ranking of specifications related to 2006–07. Achieved (A) quality, not achieved (B) quality and the weight of every specification are shown.

Table 2. Categories and their importance in 2007–08

Category	Question A	Question B	Question C	Total
Class methodology	20	15	11	46
Solving problems in class	25	18		43
More practical			32	32
Adequate speed/density of material presented		17	14	31
Proposed content	13	7	3	23
Office hours and study groups	7	14	2	23
Collection of problems	21			21
Professors	21			21
Notes and supporting material		17		17
Acquired competencies	11			11
Exams		3	3	6
Other	3	2	1	6
Same exam difficulty as class difficulty		4		4
Clarity of explanations		4		4

observed changes are minor, but they do exist: the weight of the category *Consultations* has decreased and in exchange the weight of the category *Proposed Content* has increased.

As for question "B" (unsatisfactory aspects) surveys from both iterations seem to be heavily dominated by the topic of exercise-set resolution in class, teaching material and consultations (more seminars for 2007–08). The main differences come from the remarkable emergence of the topic *speed/density of material* and the increase in importance of *methodology*.

The results appear to be consistent in the sense that they indicate a fundamental continuity of the students' evaluation of the course; which is indeed logical given that the introduced changes have not been radical.

The corresponding QFD matrix was constructed and the weight of each of the specifications obtained with respect to the satisfaction of the expectations of the students.

3.2.2 Comparison of results

In the matrix for question "A" the most notable change is the sharp decline in importance of *Consultations*. The remaining *items* of importance maintain similar levels.

As for question "B" the results for the main categories are practically identical to those obtained in the first course. The only change is the increase in importance of *allotment of time according to topic importance*, which was somewhat lower the previous year. One striking result was the fact that *Seminars* continue to appear as a lacking or deficient aspect, which was also observed in the previous year. It should be noted that seminars were not included in the 2006–2007 academic year, and that these were only introduced beginning with the 2007–2008 year. The fact that they continue to be seen as inadequate makes one consider the appropriateness of augmenting the number of offered sessions.

Lastly, comparing results from question "A" and "B," a notable difference is the clear improvement in the proportion between "quality achieved" and "expected quality" (Fig. 7).

If we compare this diagram with the first iteration's diagram (Fig. 6), we see that the important aspects for quality have not changed:

1. Number of problems per session
2. Proportion of theory/practice
3. Collection of exercise-sets
4. Number of new concepts per session.

The main change has occurred with respect to office hours and the seminars. The value and importance regarding office hours has diminished, while the demand for seminars has remained the same.

In order to measure the change of perceived quality we have calculated the variations of the values associated with each specification (Figs. 6 and 7) for each of the two questions. The result is shown in Fig. 8.

Next, the values of variation in the assessment of quality, for each specification, were shown as points within a plane, taking as coordinates the resulting variations of questions "A" and "B." This representation is given in Fig. 9. The points plotted to the right of the dotted diagonal line represent the specifications that have achieved an overall improvement regarding their perception of quality (variation A + variation B > 0).

In the graph, three distinct groups of points emerge. The first of which is a series of points very close to the line of zero variation that we can consider as specifications whose value, as judged by the customer, has not varied significantly.

The second group is a series of points that represent the specifications that have experienced an improvement in the perceived quality from the 2006–2007 academic year to the 2007–2008 course. Among these specifications there exists a clear difference between those that were put in place only after the analysis of the 2006–2007 course; more specifically, they were: number of new concepts per session, seminars, collection of problems, proportion of theory/practice and number of exercises per session (grouped in the figure). This finding confirms that the improvements introduced owing to the QFD analysis have indeed created an increase in the perceived quality, as intended.

The third group of points consisted of a grouping that signaled a negative variation in perceived quality. Among these we find the specifications of consultation hours and number of students attended to per consultation session. It should be noted that the decline in quality is due almost entirely to the "A" axis, which signifies that there has been a decline in satisfaction generated by these specifications but that there has not been an increase in the dissatisfaction regarding these specifications. We interpret that these variations are a direct consequence of introducing seminars in the course. This addition diminished the hours dedicated to consultations and the number of students attended to in them. This correlation is expressed in the roof of the "House of Quality" (Appendix III) as a strong negative correlation between these specifications and the seminars.

Similarly, two points appear above the positive "A" axis: they refer to the specifications "number of examples" and "Number of exercises solved by students in class." In both cases, the net increase of perceived quality is solely due to an increase in the satisfaction (without a decrease in dissatisfaction). If we look again at the correlation matrix of Appendix III, we will observe that both specifications maintain a positive correlation with the specification "seminars." All of this confirms the consistence of the methodology utilized.

A proposition for improvement for the next academic year could be an increase in the number of seminar sessions for the following reasons.

1. They have been integrated into the class structure and have been proven to work satisfactorily.
2. After having implemented seminar sessions, there appears to be a significant demand for even more of these sessions.
3. The existence of correlations of seminar sessions with other important factors, which are: number of exercises solved by students in class, proportion theory/practice, number of exercises per session and others (number of examples, number of practical applications, number of questions for students) shows that, by improving the specification "seminar" it is likely that these other items and the satisfaction generated by them will also improve.

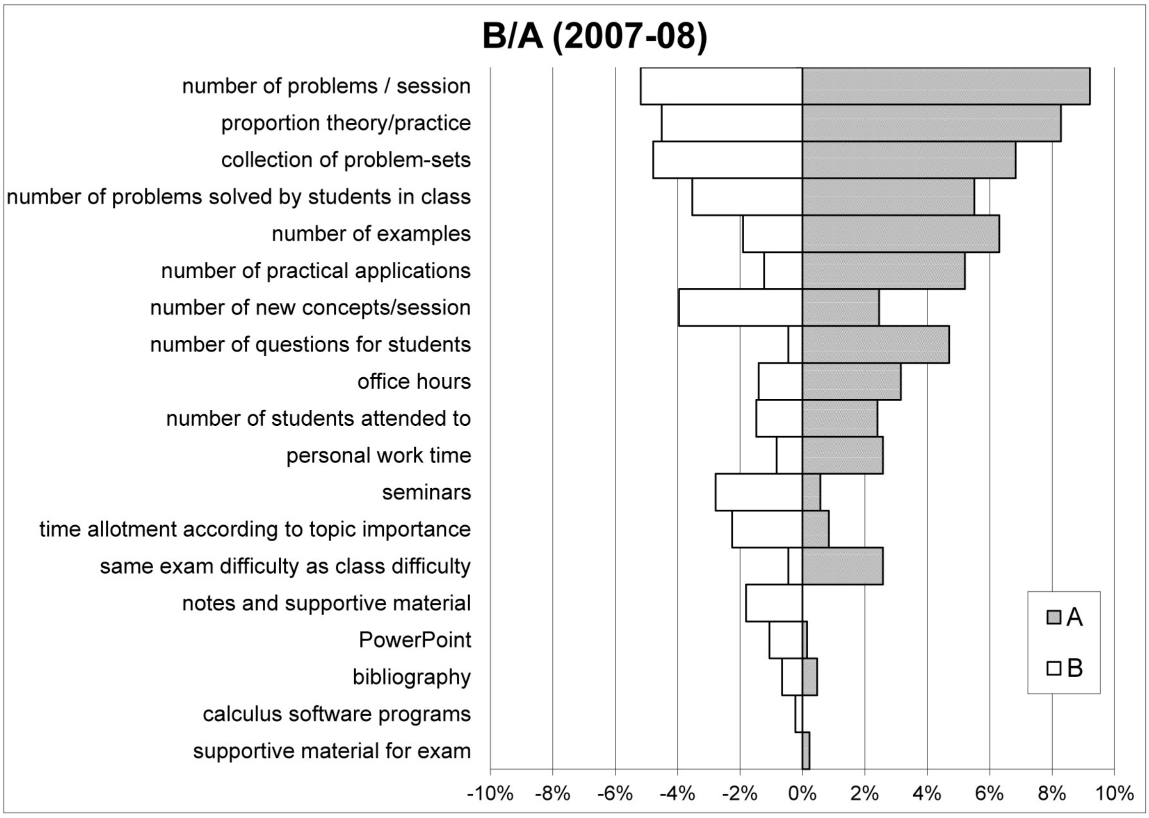

Fig. 7. Diagram of specifications related to 2007–08.

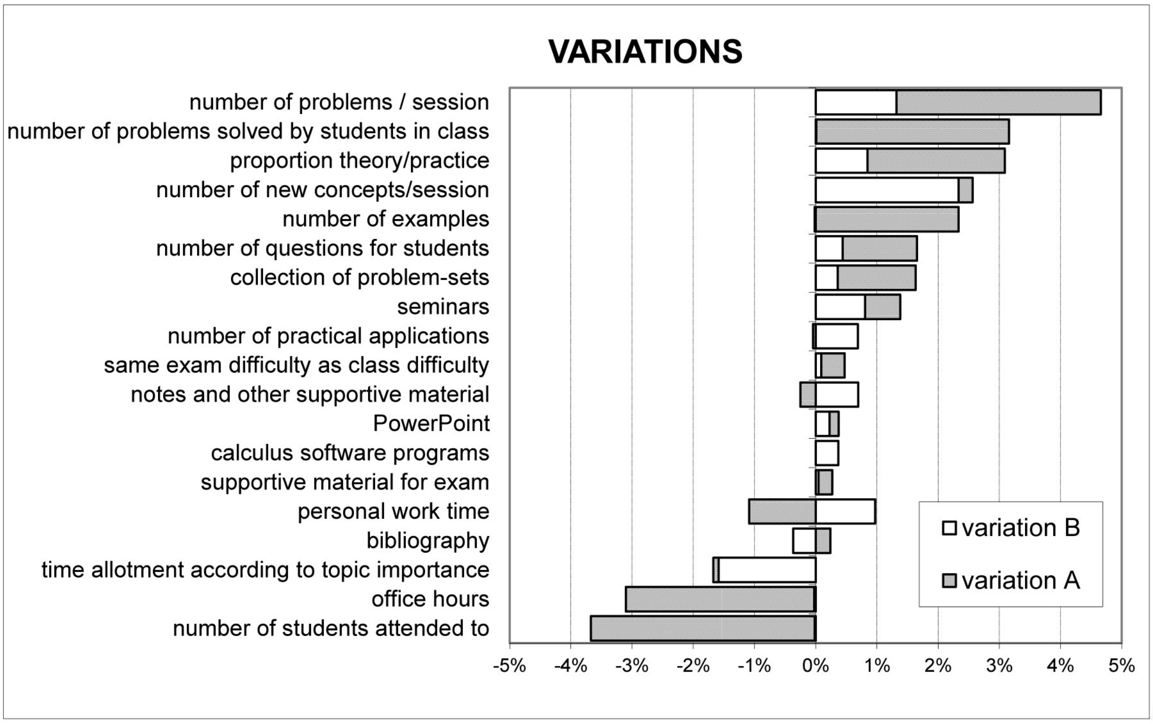

Fig. 8. Variation of the weight of every specification, and the contribution to these variations due to the satisfaction growth (A) or due to diminishment of dissatisfaction (B). The specifications are ordained by the algebraic sum of both variations.

4. The correlations (Appendix III) with consultations are negative, and as such a decrease in their demand would be expected. This would allow an increase in efficiency for the professors if they were to dedicate to seminar sessions part of the time they actually spend handling consultations.

4. Discussion

As previously stated, various published studies show the application of the QFD technique to higher education. However, the methodologies used are quite varied. Raharjo et al. [24] present five conflicting points: the form of evaluating various topics of customer voice, the method to determine the aggregate value of said topics, the form of establishing the interrelation between customer requirements and specifications, the lack of flexibility at the time of using the method and the tendency to mix different types of customers in one single matrix.

Regarding the customers who must be kept in mind, the various studies considered take into account different options: only students to improve the quality of teaching [17–20], former students [7] or graduate students with professional experience [23], students and employers but for different reasons [5], students, professors and employers [4, 24], or only employers for the design of the curriculum [21, 22]. Despite the variety, consistency is observed in all studies, following the aforementioned criteria of Mazur [10], according to which the opinion of the employer is more important for the design of the curriculum, while the opinion of the students is more significant for the design of the teaching and course style. In our work we have followed these criteria and we have kept our focus on the students, since the goal is to improve the teaching.

Concerning the application of QFD, the majority of articles cited were dedicated to the betterment of graduate level and management courses [4, 7, 10, 22, 23]. In contrast, there are fewer studies [5, 19] applied to initial courses, as in our case. This is likely due to the fact that basic courses tend to be more conventional and well known, and subsequently they arouse less interest for their improvement.

In order to obtain the "customer voice", different techniques are also used: discussion groups for brainstorming or focus groups [4, 18] closed-ended questions [5, 7, 18, 23], open-ended questions [19, 20, 24] or interviews [10, 21, 24]. In our study we have opted for open-ended questions for two reasons: this was the first iteration of a quality cycle, and therefore it was necessary to avoid putting limitations on issues prior to addressing them, but in fact it was important to obtain the student opinions first. The other important factor was that the format was simple, which facilitates student participation. The disadvantage of this type of questioning is the inherent necessity to in some

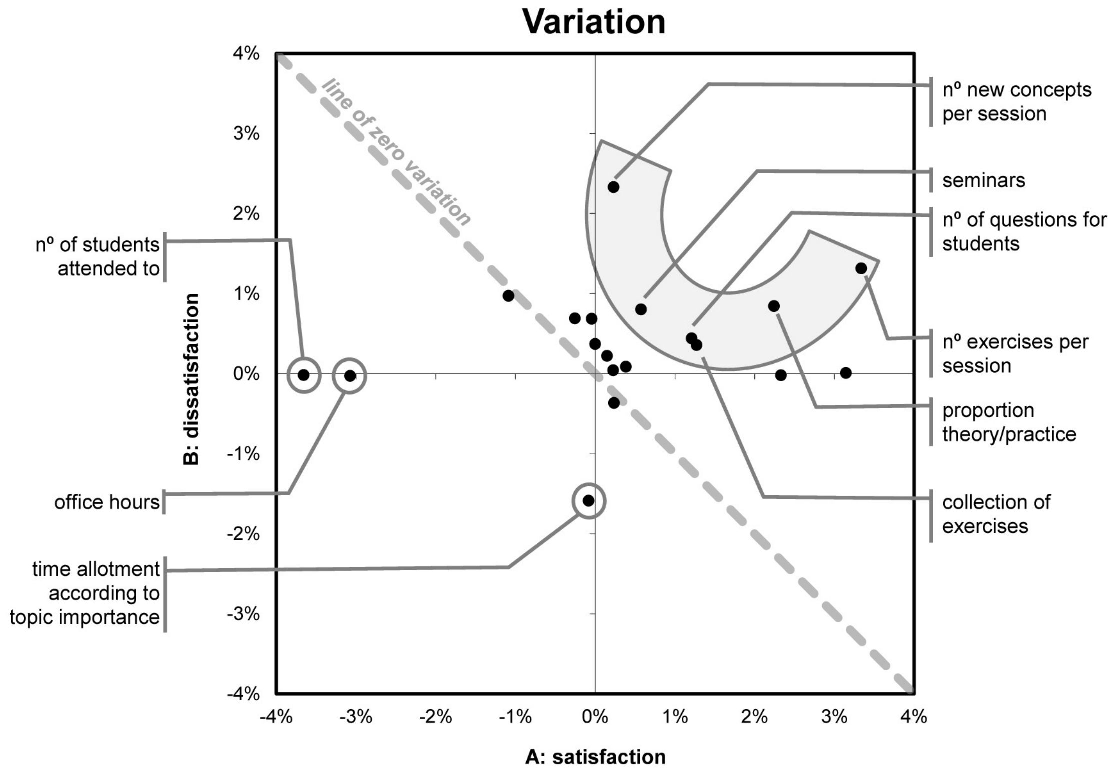

Fig. 9. Representation of the variation of perceived quality for every specification, indicating whether this variation is due to satisfaction (A) or dissatisfaction (B) feeling.

way standardize the various types of responses obtained. For this we created general categories that we maintained for the entirety of the study. Despite the seemingly arbitrary nature of this process, the results were shown to be both consistent and useful for both years of the study.

To give weight to the "customer voice", some authors who use closed-ended questions, evaluate topics by means of a scale [5, 7, 17, 18, 23]. Other authors use clustering techniques or AHP, which are indeed interesting [10, 20, 24], but they require a large amount of work with the customers. In our case we have used the frequency of responses, as an easily calculable, robust and simple measuring technique. In order to use such a technique it is necessary to first group the answers into similar categories.

Another important feature of the methodology, cited by Raharjo et al. [24], is the definition of the specifications. Usual procedures cited are: the interviewing or surveying of professors [5, 18, 23], analysis of the process [7], tree diagram or fishbone [10, 24], or they extract from the literature [19], or from the main body of research material [22]. In our case, the professors have created the specifications through an analysis of the process.

For the determination of the interrelation matrix between "customer voice" and specifications, the majority of studies considered herein have used the criteria of the authors and professors [7, 18, 23]. Lam and Zhao [18] used AHP software. In our case we also used the professor's work to establish interrelation values.

In some of the examined cases complementary and decision based techniques are applied for the analysis of the House of Quality results. In this way, Duffua et al. [5] use "design concepts" to evaluate alternatives for improvement; Lantada et al. [17] and Kaminski et al. [7] evaluate the "importance" (desired quality) and the "satisfaction" (achieved quality) and they display both variables in a two-axis graph where they calculate the relationship between both as a measure of the ability to improve each specification. Ogot and Okudan [19] have repeated their study in successive years, thereby evaluating the improvement in satisfaction. In our case we have used a Pareto pyramid (Figs. 6 and 7) to measure the importance and grade of satisfaction associated with each specification; we also repeat the study in order to evaluate the achieved improvement regarding satisfaction.

In our study we have used two QFD matrices: one for the quality achieved (A), and another for the quality not achieved (B). This allows us to gather information that may otherwise go unnoticed. This is as a result of the following four cases: some factors' absence can result in dissatisfaction, and in some cases a factor's presence does not constitute added quality; inversely, some factors' absence may be insignificant, but their presence would actually result in an increase in customer satisfaction. Also, it is possible for specifications to be simultaneously valued as satisfactory and dissatisfactory. For example, in our case, in the first iteration it was found that students desired seminars. Then, in the second course we answered this demand by putting in seminars, but the result was mixed in that students were satisfied with the introduction of seminars, but were dissatisfied with the small number and they continued to desire more, thus resulting in simultaneous satisfaction and dissatisfaction.

This methodology described is applicable to any other subject, in which it is desirable to improve the quality of teaching while simultaneously pursuing students' comfort and motivation levels with respect to class participation, in order to obtain improved learning outcomes. It is not applicable, however, to designing the actual content of an undergraduate course, given that at this level students are not able to provide input on what material is taught but, more precisely, on the manner in which the already established subject matter is presented.

This tool is useful, but ought to be complemented with others to achieve an overall and sustained improvement of teaching quality. This approach alone does not lead to radical changes in teaching methods, but through the use of open questioning, there may appear room for the implementation of innovations suggested by the students.

Moreover, the marginal improvements in successive cycles of development are likely to provide less and less satisfaction increases, trending asymptotically towards a certain level. To achieve "level jumps" it will be necessary to consider more fundamental changes in teaching methods.

5. Conclusions

In this paper, a methodology has been designed to facilitate continuous improvements of teaching, drawing on well-known tools (QFD, Pareto, etc.) arranged and adapted to our needs.

This methodology consists of:

1. Construction of a QFD matrix of a course by adapting the specifications of the course according to student opinions obtained by way of a survey.
2. The results obtained were used to formulate an improvement plan to be studied by those responsible for the course. From these proposals have come modifications to alter the way that the course is taught.
3. The study can be repeated, affording the opportunity to evaluate the effectiveness of the implementation of the past actions taken to improve the course, and also thereby closing a cycle of continual improvement.
4. The bar graphs (Figs 6 and 7) show that the ranking of specifications also facilitates a visible representation of their importance on perceived quality. Comparing these graphs over successive years, the evolution of perceived quality over time becomes apparent.

Based on our experience, the main advantages of this methodology are:

(a) The core of the survey was the inclusion of two open questions that allowed the students to directly name the positive and negative features of the course, allowing the ability to detect expectations that might otherwise go unnoticed. The responses are grouped into successive levels of aggregation, allowing quantification of the "voice of the customer."
(b) It allows for the correlation of "student opinion" with the characteristics ("specifications") of the teaching practices. This is achieved by assigning a weight, and giving priority to those changes that will increase student satisfaction.
(c) The diagrams in Figs 8 and 9 allow for an evaluation of whether or not quality was effectively improved.
(d) This methodology is useful for improving the teaching of subjects in the first years of engineering studies, even in those subjects in which the content is clear-cut and does not allow great variation, such as the introduction to Calculus.

In closing, it must be stressed that the procedure outlined within this work is easily employable while requiring neither specific training not special resources to obtain significant results regarding the improvement of perceived quality of teaching as viewed by the students.

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APPENDIX I: HoQ—QUESTION "A"—2006–07

A			Teaching material			Supportive material		Time distribution of class				Class dynamic				Office hours				Evaluation	
			Collection of problem-sets	Notes and other supportive materials	Bibliography	PowerPoint	Calculus software programs	Proportion of theory/practice	Number of new concepts per session	Number of problems per session	Personal work time	Number of examples	Number of practical applications	Number of questions for the students	Number of problems solved by students in class	Office hours	Number of students attended to	Seminars	Time allotment according to topic importance	Similar test difficulty as class difficulty	Supportive material for the test
Problems	Problem solving sessions	22	3					9	1	9		3	3	3	3				1	3	
	Abundance of problems solved in class	6	3					9	1	9		9	3	3	9					3	
	Problems (unspecific)	5	3		1			3													
	Collection of problem-sets	1	9					3			9		3			3	3			9	
Teaching Material	Collection of problem-sets	20	9					3		1	9		9							3	
	Quantity of assigned problems	5	9					3		3	9		1		3	3	3				
	Blackboard (unspecific)	3	3	3	3							1	1								
	Variety of assigned problems	2	9		1			1		3		1	3							1	
	Notes	1		9	1			1	1			3	3								
	Solution of assigned problems	1	9								3					3	3				
Office Hours	Office Hours (unspecific)	21									1					9	9				
	Help from professor	2										1		1		9	9				
	Office hour schedule convenience	1														9	9				
	Profs. available for office hours	1														9	9				
Methodology	Classes (unspecific)	11						3	3	3		3	3	3					3		
	Methodology (unspecific)	8	3					3	3	3		3	3	3	3				1		
	Good explanations	4							3	3		9	3	3		3	3				
	Interaction/participation	2							1	1		1		9	1						
	Combination of theory/practice	1						9	3	3	1	9	1						3		
	Dynamism	1						3	3	3		3	1	9	3						
	Class rhythm	1						1	9	9		3	1	9	3						
	Classes for resolution of doubts	1							3	3						1	1				
	Teaching	1						9	9	3		9	3	9							
Professors	Student care	17												1		9	9				
	Professors (unspecific)	10																			
	Clear explanations	10							3	3		3	1	3		1	1				
	Availability of professors	2														9	3				
	Preparation of professors	2										1	1								
	Sympathy of professors	1																			
	Quality of professors	1																			
			393	18	17	0	0	427	157	415	259	281	371	247	167	440	428	0	66	155	0

Fig. 10. HoQ. Question "A" (2006–07).

APPENDIX II: HoQ—QUESTION "B"—2006–07

B			Teaching material			Suppor-tive material		Time distribution of class				Class dynamic				Office hours				Evalua-tion	
			Collection of problem-sets	Notes and other supportive materials	Bibliography	PowerPoint	Calculus software programs	Proportion of theory/practice	Number of new concepts per session	Number of problems per session	Personal work time	Number of examples	Number of practical applications	Number of questions for the students	Number of problems solved by students in class	Office hours	Number of students attended to	Seminars	Time allotment according to topic importance	Similar test difficulty as class difficulty	Supportive material for the test
Problems	Problem solving sessions	27	3					9	9	9		3	1	1	3	1	1			1	
	Additional practice	8	3					9	9	9	9	3	9		9				1		
	Problems (unspecific)	2	9					9		9	9				9			3		1	
	More practice problems	1	9	1	1		9	3	3	3		1	9					3			
	Clear resolution methodology	1		1						3	1	3		3	3	3	3	3			
	Planning of study-groups	1									3										
Teaching Material	Answer to all assigned problems	24	9								1										
	Graphical support	6		9		9	3			3			1								
	Electronic notes	3		9	1	3		1	1			1	1								1
	Solved test questions	3		9																3	
	More material (without specifying)	3		9	1	9	3														
	Solved problems available for use	3		9	3						3										
	Applications to the real-world cases	2	3	3	1		3						9								
	Problems order according agenda	1	9																3		
Office Hours	Seminars	23								3					1			9			
	Office Hours (unspecific)	7														9	9	1			
	Wait time for meetings	1														3	9				
	Shared-work sessions	1													3			9			
Methodology	More time per topic	11						3	9										3		
	Solve problems individually in class	4						1	1	3					9						
	More interactive classes	3										1		9	3						
	More examples	2		3	1			1	1	1		9									
	Classes dedicated to solve doubts	1								1					3	1	1	9			
	Shared work sessions	1																9			
Profess or	Slower tempo	2							9	9				3	1						
	More punctual	1																			
	Better organization in explanations	1																	3		
			363	176	20	90	42	378	444	459	127	133	135	63	250	97	103	253	47	38	3

Fig. 11. HoQ. Question "B" (2006–07).

APPENDIX III: CORRELATION AMONG SPECIFICATIONS (2006–07)

		Teaching material			Suppor-tive material		Time distribution of class				Class dynamic				Office hours				Evalu-ation	
		Collection of problem-sets	Notes and other supportive materials	Bibliography	PowerPoint	Calculus software programs	Proportion of theory/practice	Number of new concepts per session	Number of problems per session	Personal work time	Number of examples	Number of practical applications	Number of questions for the students	Number of problems solved by students in class	Office hours	Number of students attended to	Seminars	Time allotment according to topic importance	Similar test difficulty as class difficulty	Supportive material for the test
Teaching material	Collection of problem-sets			#		#	&		@	@		@			#	#			#	
	Notes and other supportive materials			#	@			#		#	@	@								
	Bibliography										#	#								
Sup. Mat.	PowerPoint							@	@	@	#	#								
	Calculus software programs								&	#		@					@		x	
Time distribution	Proportion of theory/practice							@	x		#			x			x			
	Number of new concepts per session								x		x	&	&	x						
	Number of problems per session									&	@	#	x	@	&	&	@		#	
	Personal work time														#	#	@			
Class dynamic	Number of examples											#		#		&	#		#	
	Number of practical applications																#			
	Number of questions for the students													x			#			
	Number of problems solved by students in class														x	x	@			
Office hours	Office hours															@	x			
	Number of students attended to																x			
	Seminars																			
	Time allotment according to topic importance																			
Eval.	Similar test difficulty as class difficulty																			
	Supportive material for the test																			

Fig. 12. Correlation among specifications (2006–07). Key. @ = strong positive, # = weak positive, & = weak negative and × = strong negative.