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Artificial intelligence approach to support statistical quality control teaching

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Abstract

Statistical quality control – SQC (consisting of Statistical Process Control, Process Capability Studies, Acceptance Sampling and Design of Experiments) is a very important tool to obtain, maintain and improve the Quality level of goods and services produced by an organization. Despite its importance, and the fact that it is taught in technical and college courses, as well as in companies' training sectors, SQC has been largely misused. An inappropriate teaching approach may be the cause of such problem; therefore it has motivated the development of a model for SQC teaching, allowing its learners to correctly apply SQC techniques. After a survey regarding the concept needed to correctly apply SQC, its use and teaching/training methods, the model's contents and methodology were defined. We also realized the opportunity of incorporating a computer environment for the model, permitting the practice of the needed SQC concepts and skills. An Artificial Intelligence approach was used to develop the computer environment, resulting in an Intelligent Tutoring System, the STCEQ. The paper discusses the main characteristics of the system, its functioning, benefits of using such a system and the results we obtained while using this system.

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1. Introduction

Statistical Quality Control (SQC) had been used for more than 70 years around the world, and it has greatly contributed to improve the quality of many goods and services. In spite of its widespread use, SQC is often misused, either by choosing inappropriate techniques to solve the problems or ignoring the underlying assumptions to use those; techniques (Alwan & Roberts, 1995). This situation occurs not only in Brazilian companies (Epprecht & Machado Neto, 1996) but also in other countries (Bränstrom-Stenberg & Deleryd, 1999; Dahlgaard, Kristensen, Kanji, Juhk, & Sohal, 1998; Lee, Leung, & Chan, 1997).

One of the causes of such SQC misuse can be the inadequate training: those who could use SQC techniques did not fully understand the concepts and the necessary assumptions. Therefore we decided to develop a model for teaching Statistical Quality Control, which would incorporate a computer environment to practise concepts and skills. The model's contents and methodology were defined after a survey regarding use and teaching of SQC methods. An additional research effort regarding computer applications for teaching SQC recommended an Artificial Intelligence approach for the computer environment. The system was called STCEQ (Sistema Tutorial Inteligente para Controle Estatístico da Qualidade) – Intelligent Tutoring System for Statistical Quality Control, which could provide a friendly environment to learn and practice SQC (Reis, 2001).

2. Statistical quality control: concepts, use and teaching

Statistical Quality Control is defined in this work as (Western Electric, 1956): "with the help of numbers, or data (Statistical), to study the characteristics of our process (Quality) in order to make it behave the way we want it to behave (Control)." The main issue is quality evaluation, because quality is vital to the organization survival and growth. Therefore one needs to systematically study a process variability to assure its quality. The only way of doing it is by using statistical methods.

There are four major components of Statistical Quality Control: Statistical Process Control (SPC), Process Capability Studies, Acceptance Sampling and Design of Experiments.

Statistical Process Control includes Control Charts, which monitor a process performance, and some "opportunity tools," like the Ishikawa diagram and the fluxogram, and statistical tools, like the Pareto diagram and the histogram (those tools are used to find the causes of a process misbehaving, perhaps an opportunity for improving its quality).

Process capability studies measure the process' ability of producing items according to specifications, which is crucial for quality assurance.

Acceptance Sampling can be defined as the group of statistical techniques used to accept or reject lots of finished goods or raw material received from suppliers, based on random samples

taken from those lots. Duncan (1986) emphasizes that Acceptance Sampling does not estimate lot quality, it just recommends a course of action: to accept or reject the lot.

Design of Experiments is a broad statistical issue. Properly designed statistical experiments can discover what variables are causing a process to misbehave and also the magnitude of the effect.

The survey by several researchers regarding use of SQC provided some interesting results (Bränstrom-Stenberg & Deleryd, 1999; Dahlgaard et al., 1998; Lee et al., 1997; Reis, 2001):

- Control Charts techniques (especially Shewhart Control Charts) and Process Capability Studies (with less emphasis) are the most used SQC tools in places as different as the USA, Sweden and Hong-Kong;
- the Eastern companies, however, seem to be more aware of not only SQC but also of quality management as whole;
- an ISO 9000 certificate does not mean that the company is actually using SQC, despite of most certified companies stated their commitment to quality;
- in some situations, SQC implantation was done only by customer's requirement, especially in companies which are suppliers for the automobile industry;
- the most important SQC skills are results interpretations (especially from Control Charts), and problem-solving using statistical information (they should be developed in any teaching/training program).

From the survey regarding teaching SQC on Brazilian higher education courses (Engineering and Statistics), [1] the main results are:

- in the Engineering programs SQC is usually covered in one course only, an elective one many times, while in the Statistics programs it is mandatory;
- usually the SQC courses include SPC and Acceptance Sampling (nevertheless the latter is losing importance);
- the SPC topics focus at Control Charts, especially the Shewhart ones, the "advanced" charts (like CUSUM and EWMA) as well as Process Capability studies are barely covered;
- Design of Experiments is sometimes covered in a separate course, often in Statistics programs (as expected);
- the main deficiency seems to be the time (lectures and practical activities) allocated to SQC courses (45 h is usual, with only 30 h in some cases), which is probably insufficient to properly cover Control Charts and Process Capability Studies;
- management issues should be included in the SQC course (or courses), at least the conception of the organization as a system, and its impact on quality management (Neave, 1996).

Based on the conclusions obtained from the two surveys and additional research efforts (Hong & O'Neil, 1992; O'Sullivan, 1995), we have defined the contents and methodology to be embedded

[1] The majority of Brazilian SQC practitioners with higher education is composed of Engineers and Statisticians.

into the model for teaching SQC, and the opportunity to include a computer environment. Further research (Kearsley, 1987; Nievola, 1995; Pozo, 1991; 1996) showed that an Artificial Intelligence (AI) approach could be a good option to implement the computer environment for an Intelligent Tutoring System (ITS). The reason for such decision was its ability to create a "learn-by-doing" environment, in which the student/trainee can develop the needed SQC skills and long-lasting knowledge (Clarkson et al., 1994; Du Plessis, Van Biljon, Tolmie, & Wollinger, 1995; Reis, 2001; Wenger, 1987). The ITS was called STCEQ. In its current version STCEQ includes only problem-solving activities to SPC and Process Capability Studies. However, tutorials for Acceptance Sampling and Design of Experiments were added to provide a complete description of Statistical Quality Control.

3. STCEQ concepts

STCEQ was developed using artificial intelligence to build a learning environment for Statistical Quality Control, as part of a teaching model. The research relied on our previous experience with using artificial intelligence to support Statistics teaching, the SEstat expert system (Cechinel & Moreira, 1998; Cechinel, Reis, Ohira, & Nassar, 1999), The research work on this system still continues (Dias, 2000). Despite its usefulness, SEstat does not address SQC issues, nor provides a constant monitoring of user's answers, which might be of great help in a learning environment. In addition, SEstat would have been practically rebuilt to accomplish some features, like simulation, that one wanted to have it in a SQC learning environment. Therefore one decided to develop a new application, called STCEQ.

STCEQ is an Intelligent Tutoring System (ITS). Here an ITS is understood as a computer program which uses artificial intelligence techniques to simulate human thinking in a certain domain, attempting to help an "apprentice" in building strategies to solve problems or take decisions (Fowler, 1991). Intelligent Tutoring Systems are also known as ICAIs (Intelligent Computer Assisted Instruction) or Knowledge Communication Systems (Wenger, 1987). The idea was to create an environment in which a user could freely search for SQC concepts and could solve real SQC problems under supervision (automated supervision).

Among its requirements STCEQ includes items, such as the following:

1. *Friendly environment.* STCEQ provides a friendly learning environment, minimizing the time needed to master the system interaction, thus allowing the user to get down to business as soon as possible. STCEQ includes two ways of interaction, free consultation of tutorials, or solving SQC problems. In the former the user navigates SQC tutorials as in a multimedia document and in the latter he answers items regarding a production process.
2. *Real SQC problems.* The problems embedded in STCEQ are "real" SQC problems, with real production flows and real data. Unfortunately obtaining real data was quite a task; very few Brazilian companies permitted their data to be used, even with a promise of not using the real company name. Therefore we decided to simulate the data using a random number generator. However, the production flows used are real ones. The problems include interpretation of results, choosing and detailing techniques, and choosing what to be evaluated in order to monitor and improve quality.

3. *Supervision.* An SQC expert and a tutor are embedded in STCEQ. The former is responsible for the "correct" answers to the questions, and the latter compares user's and expert's answers, calculates user's performance, and suggests what he should do next (next problem to solve, which tutorials to consult).

STCEQ also shows a user's activities in previous interactions (tutorials consulted, problems solved, performance), allowing the user to plan a better course of action. And, last but not the least; the user has full control of the interaction: he can choose to follow or ignore tutor's recommendations.

4. STCEQ structure

STCEQ is a modular system, using an object-oriented approach. This allows future expansion and also turns maintenance easier. Its structure includes the following modules:

- *Apprentice.* It stores information from all STCEQ users; each user is an instance of this module. Every time a user accesses the system the related information is updated, and user's previous activities (problems solved, performance and tutorials consulted) are presented, to give directions to the new interaction.
- *Simulator.* It includes a random number generator, and all Statistical Process Control techniques (Control charts and capability studies). It generates all results (graphics, numbers) used in problems and tutorials. Its algorithms (Dachs, 1988) were statistically tested for randomness and distribution fitting.
- *Problem.* It stores all problems that can be presented to the user (including the tutorials associated with each problem); each problem is an instance of this module. It also sends the needed information to the Simulator module to generate the proper data and to the Expert module to reason about the questions.
- *Tutorial.* It stores all tutorials that can be consulted. Each tutorial is an instance of this module.
- *Expert.* It solves the problems along with the user and evaluates his/her performance. It also sends all conclusions to Tutor module.
- *Tutor.* It contains all pedagogical information, and based on Expert conclusions presents a diagnosis about user's answers, and the best course of action to take next. It also updates Apprentice with the problem just solved and user's performance on it.
- *Interface.* It presents all information to the user. The interface was written in Portuguese, aimed at Brazilian users.

Fig. 1 summarizes STCEQ structure. The tutorials were developed as Microsoft PowerPoint™ presentation files, which can ease the maintenance. However, in the next versions simulation will be included in the tutorials, allowing the user not only to generate data but also to use it in order to learn and practice SQC concepts. The problems' presentations (company description, production process, quality problem) were also implemented as Microsoft PowerPoint™ presentations, but the results come from the Simulator module.

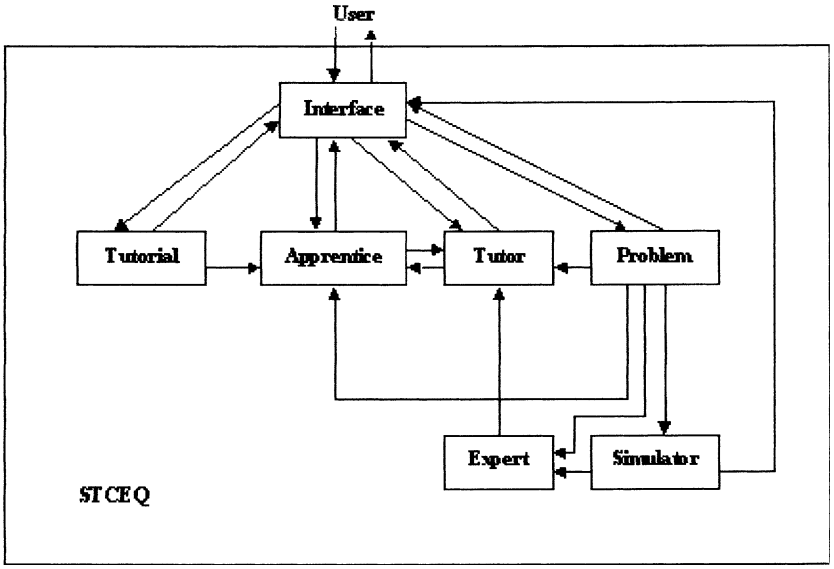

Fig. 1. STCEQ structure.

STCEQ has been developed as a stand-alone application (in near future we intend to build a web-based version) in a Windows-based, IBM-PC compatible platform. An expert-system shell, Intellicorp Kappa-PC 2.4™, has being used to develop the prototype. Quality Control or Statistical Quality Control course.

5. Possible ways of interacting with STCEQ

Some STCEQ screens are presented in the next figures (they are originally in an 800×600 pixels size and are written in Portuguese, we provided the needed translation).

Once the user identification is done, the Apprentice module will present a report with all previous activities (Fig. 2). If the identification match is not found the user is considered a first time user and is presented with a welcome message and recommendation to solve the first problem.

In the upper left comer are the freely consulted tutorials (titles and description); those which were accessed by the user without a recommendation from the Tutor module. In the lower left corner are tutorials that user had consulted when solving problems. In the upper right comer are the solved problems (number and description). Finally, in the lower right corner the performance of the user is shown. This gives the user summary of all previous activities, intending to help future choices. If the user decides to continue (CONTINUE) a main menu will be shown.

In the STCEQs main menu, the user can choose between freely consult tutorials, much like a multimedia document (as an encyclopedia), or solve some Statistical Quality Control problems.

If the user decides to consult tutorials a screen containing the major areas covered by STCEQ is presented (Fig. 3).

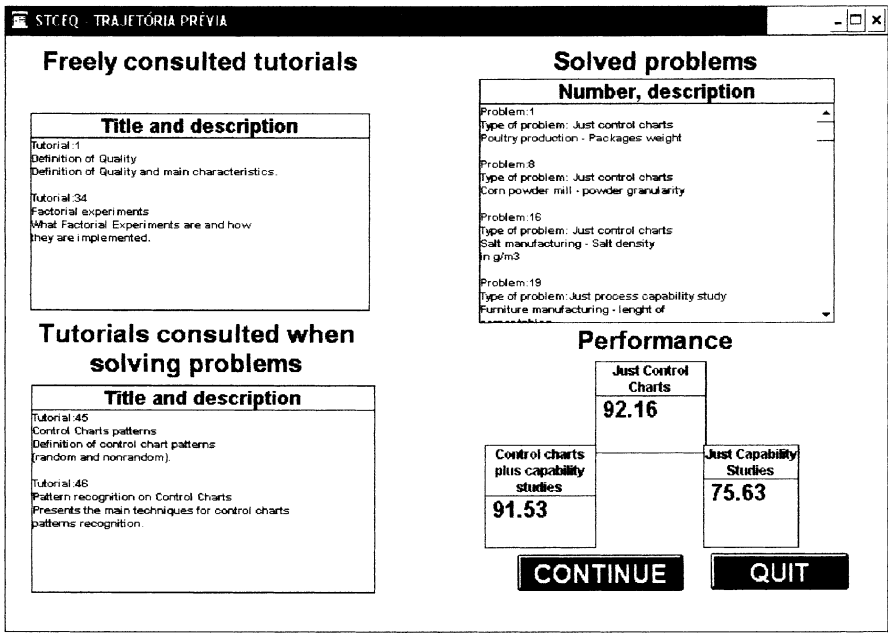

Fig. 2. User's previous activities.

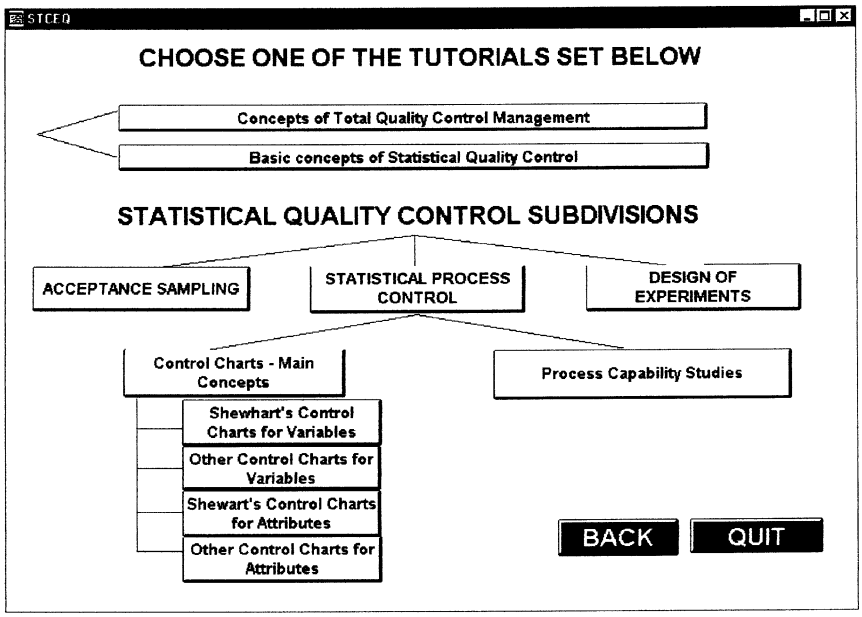

Fig. 3. STCEQ tutorials menu.

The tutorials are grouped in five main areas: basic concepts about quality and TQM, basic concepts about Statistical Quality Control, Acceptance Sampling, Statistical Process Control (with its subdivisions) and Design of Experiments. SPC was divided in two major areas for didactical rea-

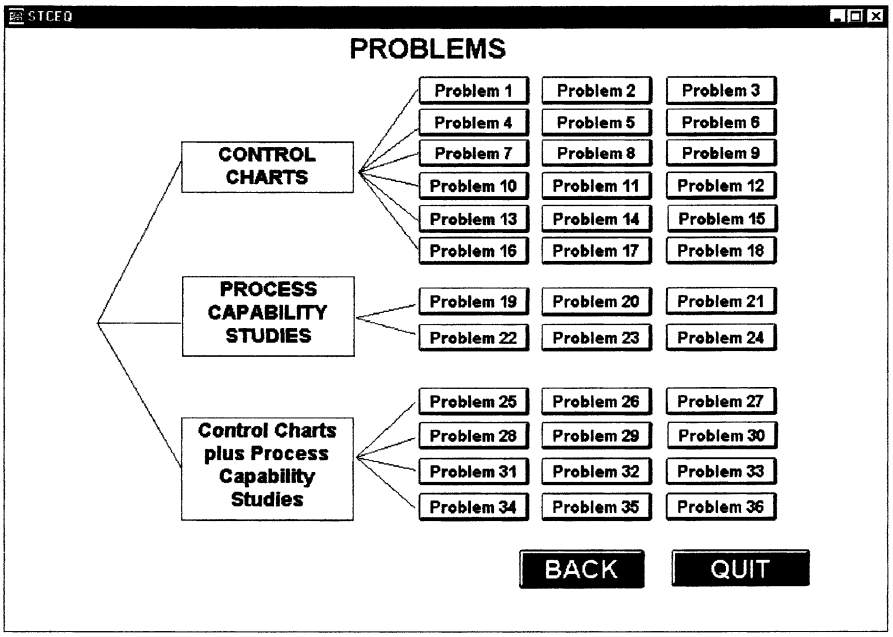

Fig. 4. STCEQ problems.

sons: Control Charts and Capability Studies. Control Charts were divided in Shewhart Variables Charts, Other Variables Charts, Shewhart Attributes Charts, and Other Attributes Charts. The user can return to the main menu (BACK), quit the system (QUIT) or go to other screens, each one with all tutorials from a specific area or subdivision.

If the user decides to solve SQC problems a screen like Fig. 4 will be shown. The problems are grouped by three major types, according to the techniques involved: Control Charts, Capability Studies, Control Charts plus Capability Studies. In the current version STCEQ has one difficulty level only: the user answers questions about the results generated by STCEQ. The problems that the user previously solved are shown in a different color; they are highlighted to prevent the user from solving them again. Moreover, after knowing the previous performance the user can make a more careful choice for the next step to take. Once a problem is chosen, STCEQ shows its description to the user, and also a Microsoft PowerPoint™ presentation about it. The user can decide to solve the problem or to return to the previous screen. Once deciding to solve it, the Problem module sends a message to the Simulator module, which produces all the results, like the X-bar and R control charts as shown in Fig. 5.

The user will answer items based on statistical results, for instance, if the process from which the charts were plotted is under statistical control and why. The Expert module will also answer the same questions, and the Tutor module will compare both answers (checking if there are differences between them and how different are they), evaluate user's performance and recommend the best course of action. The user can anytime quit STCEQ, or return to a previous step. He/she can also ignore the tutor recommendation, and choose not to consult the listed tutorials.

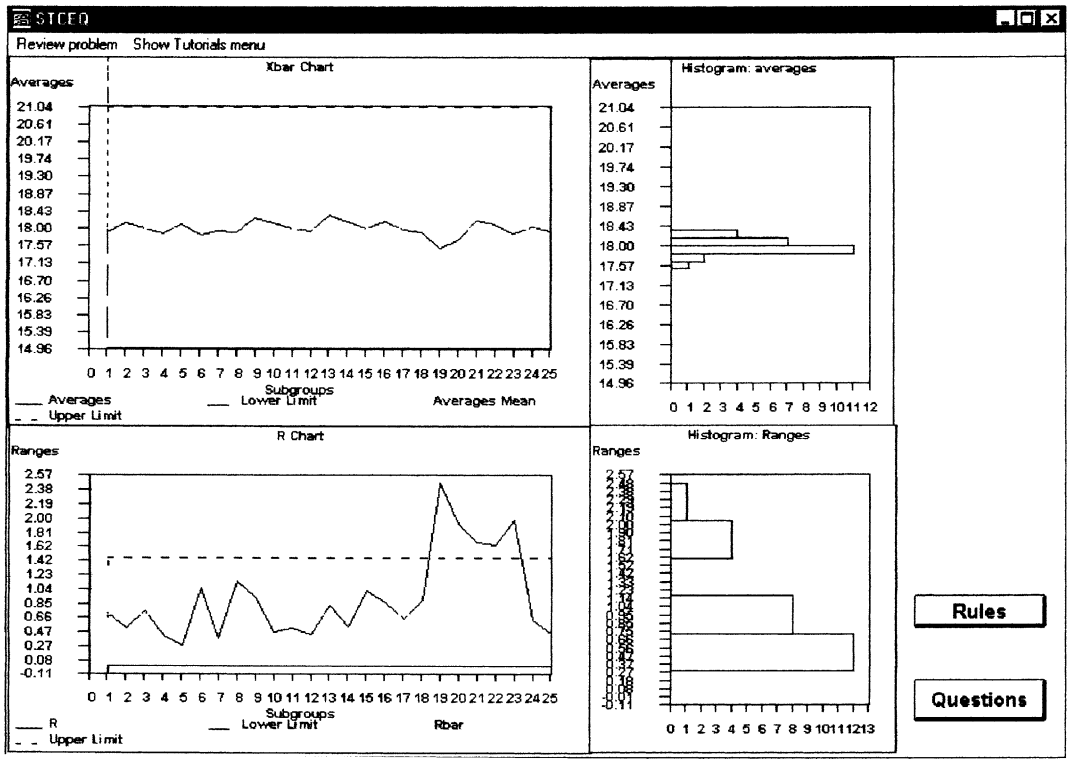

Fig. 5. STCEQs simulator module results – control charts for averages and ranges.

6. Example

A small example of system interaction will be presented. A user decides to solve SQC problems. The user must choose among those presented in Fig. 4. In this example the user chose "Problem 11". This will trigger the problem's presentation, which is shown in Fig. 6.

The presentation states the techniques involved ("Only Control Charts"), the depth ("Depth 1"), and a brief description of the problem (analysis of a poultry industrialization process). The user can really initiate the presentation (by pressing "Begin presentation") or return to STCEQ problems (by pressing "Back to problems menu"). In this example the user decided to really initiate the presentation: relevant information about the company, its production process and the quality problems are shown to the user, who can control the presentation's pace and replay it as many times. In this problem the user must analyze a p control chart in order to verify what is happening to the process. Once the presentation is finished STCEQ asks the user about the next step: solve the problem or return to STCEQ problems?

With the information provided by the Problem module (its instance "Problem 11"), the Simulator module generates the data needed to plot the p control chart. The results are presented in Fig. 7.

On the left side of Fig. 7 is the p control chart (25 subgroups, 25 fractions of non-conforming poultry. At the right side is the associated five-bar histogram of all 25p fractions (allowing the user

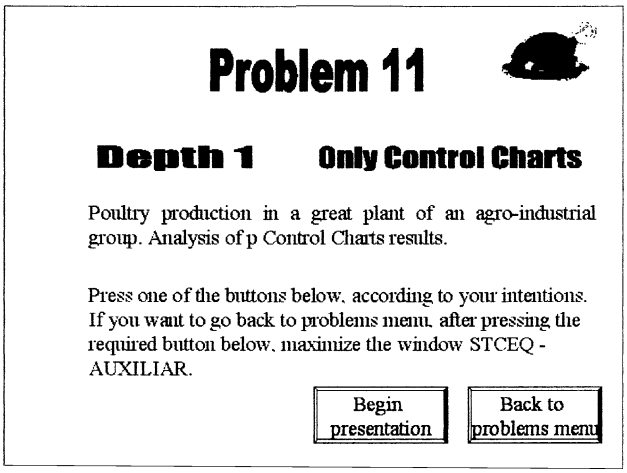

Fig. 6. Problem's presentation.

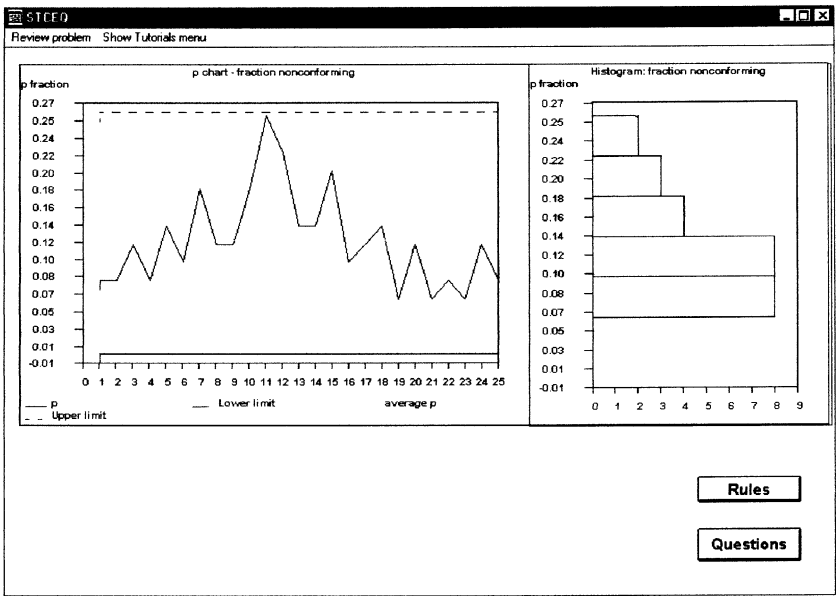

Fig. 7. *p* control chart.

to visually analyze if the data is normally distributed). On the lower right corner there are two buttons: "Rules", which will lead to a screen (not shown here) where the user can apply a series of rules to the control chart (in order to identify if the process is out of control) (Montgomery, 1997; Western Electric, 1956)) and "Questions", which will present the first two questions related to the problem. There are nine rules that can be applied to a single control chart (if there are two control charts, e.g., for averages and ranges, the rules are presented for both the charts). Based on

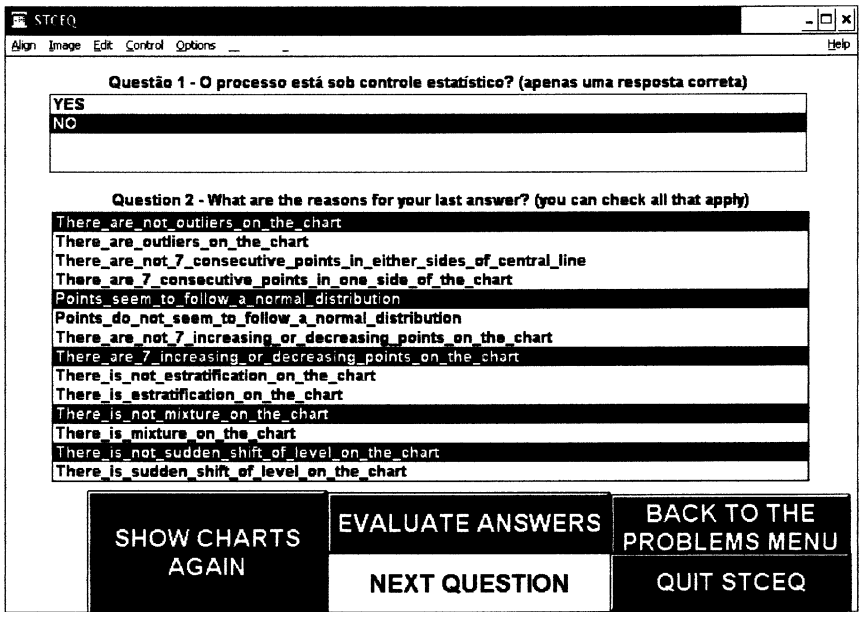

Fig. 8. Some STCEQ questions.

all the rules, and the control chart, a user can surely say that if the process is under statistical control or not. The user must decide when such rules are appropriate to be used: for instance, some rules designed for average and range control charts (in which the observations are considered independent and identically distributed) cannot be used in a CUSUM or EWMA control charts (in which the observations are related) (Montgomery, 1997).

If the user decides to answer the questions, the screen in Fig. 8 will be shown. In the first question the user will simply say if the process is under control ("YES") or not ("NO"). Only one answer is allowed. In the second question the user will state the reasons for his answer. choosing among a wide range of options, more than one option can be checked. The user must answer based on the control chart appearance and the rules result.

The user also has the option of examining the charts again ("SHOW CHARTS AGAIN"), or returning to STCEQ problems screen ("BACK TO PROBLEMS MENU"), or reviewing the problem presentation (by choosing a menu on the top of the screen), or consulting a tutorial (again by choosing a menu on the top if of the screen) or even leaving the system ("QUIT STCEQ"). Once the user had answered the question, he/she can ask the system to evaluate that ("EVALUATE ANSWERS"). The user cannot go the next question ("NEXT QUESTION"), without giving an acceptable answer to these two first questions.

How does the evaluation work? STCEQ compares user's answers with the expert's (the expert is embedded in the system). Depending on the differences found, some recommendations are made, in order to help the user to perceive the mistake (of course, if there's no mistake, a congratulation message is shown). Incomplete diagnosis is also considered, but only in some cases. To conclude that the process is under statistical control, the user must check all options which indicate that finding, but to conclude that the process is out of control, the user can check only some options

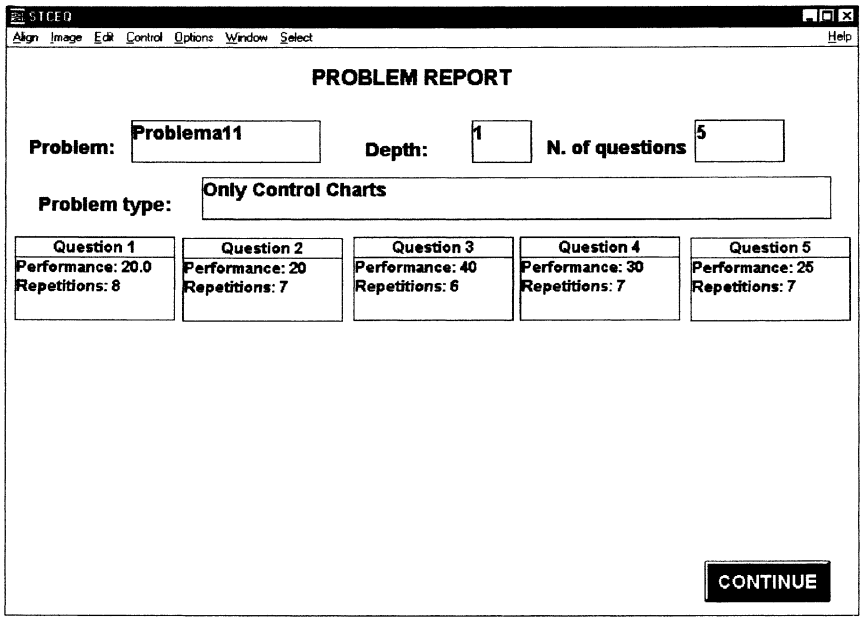

Fig. 9. STCEQ report – first part.

that were identified (an incomplete but acceptable diagnosis). This approach is used in all questions that allow multiple options to be checked.

Once the problem is finished, STCEQ prepares a report to the user. This report is divided in three parts. The first part contains some basic information about the problem just solved as shown in Fig. 9: problem number ("Problem"), problem depth ("Depth"), number of questions ("N. of Questions"), and problem type ("Problem type") – control charts only, capability studies only, control charts plus capability studies. In addition, the system shows user's performance for each question (a number from 0 to 100, 0 meaning the worst performance and 100 the best). The performance values are calculated based on the number of repetitions (wrong answers) the user gave to each question: one repetition means a reduction of 10 on performance value. Incomplete but acceptable diagnosis implies a reduction of 5 (applied only in multiple-answer questions).

The second part of the report issues a general diagnosis about user's performance in the problem just solved; it is shown in Fig. 10. The overall performance can be categorized as excellent (above 90%), satisfactory (between 70% and 90%) or unsatisfactory (below 70%). Depending on the category in which a user's performance falls, STCEQ can recommend some tutorials in order to enhance the user's knowledge about the problem: for an excellent performance no tutorial will be recommended; for a satisfactory performance, only the complex tutorials (associated with the problem); and for an unsatisfactory performance all associated tutorials will be recommended. In this case (Figs. 9 and 10) user's performance was unsatisfactory (36.32%), therefore all associated tutorials were recommended. The user is allowed to choose the tutorial in any order, or even choosing none of them and continuing the interaction ("CONTINUE").

The third part of the report presents a summary of user's performance in all types of problems previously solved (Fig. 11). It also verifies the remaining problems and recommends which one,

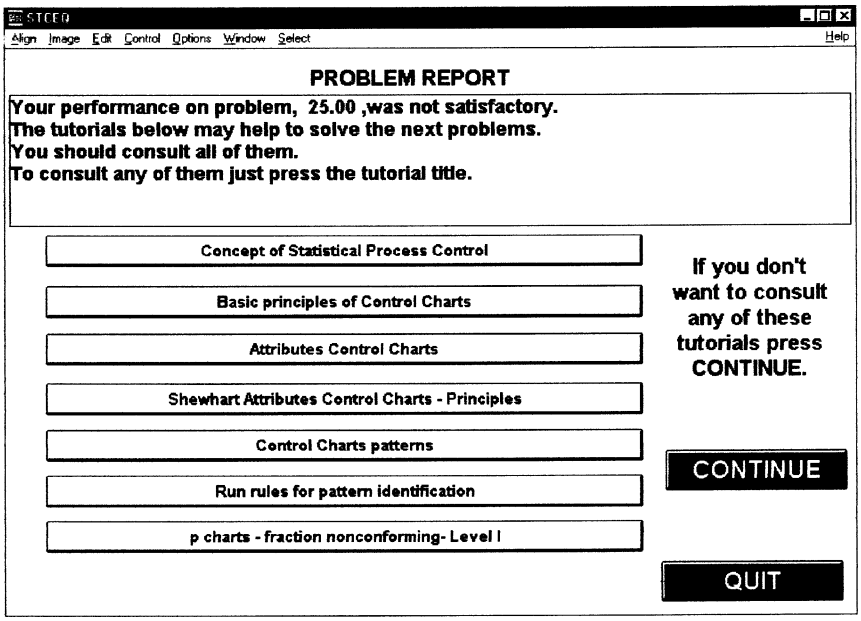

Fig. 10. STCEQ report – second part.

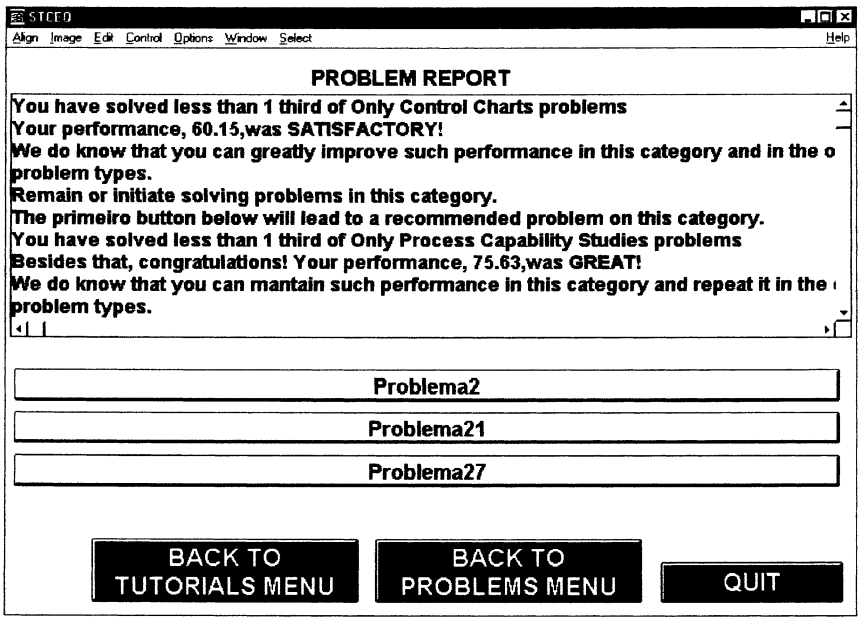

Fig. 11. STCEQ report – third part.

in each type, the user should later solve. Again, the user can choose any recommended problem, or none of them. The user can return to STCEQ tutorial menu ("BACK TO TUTORIALS MENU"), or to STCEQ problems ("BACK TO PROBLEMS MENU"), or even quit the system (QUIT).

7. STCEQ application

STCEQ is part of a model for SQC teaching, which was developed as a doctoral thesis (Reis, 2001). Before applying the ITS to an ordinary undergraduate course, we decided to conduct a preliminary evaluation, to detect any problems that could lead to unwanted results. From September 2001 to early December 2001 a group often production engineering graduate students evaluated STCEQ, in order to assess its functionality, interactivity, and its contribution to SQC learning.

The group was composed of people with different skills and previous experience. Four of them are Statistics professors, two are SQC practitioners, one is a professor and quality consultant, and three are considerably experienced system analysts. All of them have already had contact with computer assisted instruction. We believed that such group would be capable of giving many insights about the system, and also detect any existing flaws.

STCEQ was unanimously considered a very useful tool to support SQC teaching. Among the interesting features the group pointed out:

- the problems "immerse" the user in a real situation, in a real quality problem, with all the necessary information to solve them;
- the tutorials were considered well written, with a dynamic language and approach, allowing a pleasant experience of discovering SQC concepts;
- the pseudo-random number generation, which assures different results for every user, for every problem, forcing the user to really interpret the results obtained;
- the performance reports help the user's learning, indicating which tutorials and problems should be assessed after, and they also challenge the user to improve performance;
- the system allows a dynamic and interactive learning, applying the tutorials' theory in case studies (the problems);
- STCEQ can be applied almost immediately, with only minor changes.
- The group indicated some operational problems, and appearance flaws, most of them very easy to correct:
  - some spelling and subject–verb agreement mistakes;
  - some options could not be completely seen, because the scrolling bar was not installed;
  - during the tutorials and problems' presentations there is no indication that the slides are over;
  - the background colors and fonts size should have uniformity;
  - the appearance of answers' options should be changed, to ease their reading.

The main conceptual problem (unanimously noticed) was STCEQ Tutor's messages vagueness. In other words, sometimes the Tutor's messages does not give enough Information about the user's mistakes: for instance, the Tutor states "diagnosis incomplete," but it gives no hints about what is missing and what is not. This was deliberately implemented, according to some pedagogical consultants, in order to not make STCEQ's Tutor too "behaviorist." A vague orientation should challenge the user to seek for the correct answer by him. Unfortunately, this approach did not work. The evaluation group felt "lost" in certain situations, and some of them even used the trial-and-error method to find the correct answer (because of the particular SQC jargon,

previously unknown to some members of the group). Therefore, we decided to modify the Tutor, giving as much information as possible, without directing the user to the correct answer, This will be the next step on STCEQs development.

The evaluation group also gave other valuable suggestions to improve STCEQ:

- including a presentation summarizing STCEQ to begin the interaction, explaining its objectives and particular features;
- including options for printing and saving the work before the end of the interaction;
- migrating the system to a more flexible developing tool, which can produce an executable file (enhancing STCEQs portability);
- implementing tutorials and problem's presentations in a more flexible developing tool, allowing including simulations and filing exporting.

Besides the formal evaluation described, STCEQ was informally evaluated by many Engineering undergraduate students, as well as Statistics and Computer Science professors and professionals. As a whole STCEQ was also considered a very useful tool to support SQC teaching.

8. Conclusions

Despite its importance and widespread teaching, Statistical Quality Control (SQC) has been misused in many companies. One possible cause of such problem could be inappropriate training. Aimed at improving SQC teaching a model was developed as a doctoral thesis. This model included a computer environment to allow users to practice SQC concepts and develop SQC skills: the STCEQ, Intelligent Tutoring System for Statistical Quality Control.

Series of exams were conducted at Universidaide Federal de Santa Catarina, Brazil. Students and practitioners considered STCEQ a very useful resource to support SQC teaching. It seems that STCEQs features can greatly enhance the learning of Statistical Quality Control concepts. It provides a friendly environment for a practicing engineer (having previous SQC knowledge) or someone acquiring new knowledge. Because of the random number generator inside the Simulator module the user faces new situations every time the user solves a problem, even the same problem, forcing him/her to really analyze the results. The report presented with a user's previous activities helps him/her to plan the current interaction. The Tutor module provides a very good way to support learning.

We intend to expand the system, adding more difficulty levels: inclusion of problems regarding Acceptance Sampling and Design of Experiments, and interface improvement. But the most ambitious goal is to implement a web-based version of STCEQ, to make it useful for distance learning programs.

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