Abstract—The global objective of the paper is to introduce a new Statistical Process Control (SPC) education technology using an interactive control chart simulator. The basis is the contemporary experience in teaching at universities and in training for the practice and from there resulting observation, that especially the regular students often lack practical knowledge about the production process while managers lack deeper insight into the SPC theory. A possibility to eliminate this deficiency is a practical activity where individuals attain knowledge and skills through personal or hands-on experiences. Function of the simulator is to enable the student to resolve typical situations encountered in the SPC. This paper presents learning objectives, the SPC simulator concept, its functions, and the manner of its use in education.

Keywords—engineering education; statistical process control; control charts; web-based learning; simulation; learning by doing

I. INTRODUCTION

In the manufacturing industries, discrete-event modeling, simulation, and analysis often improve system robustness by helping engineers construct a better system through the elimination of bottlenecks, improvement of resources utilization, and optimization of system resources. Although discrete-event simulation provides a “realistic” platform for a better understanding of the system operation, the product and process quality dimensions of the manufacturing system are often disregarded [1].

Quincunx model that drops balls over number of pins is still considered to be the pioneer in teaching the Statistical Process Control (SPC) simulation. Currently, this mechanical tool is upgraded by training software [2], while further providers of similar SPC tools are Statistical Solutions [3], SPC Simulator [4] and others. Nonetheless, majority of such tools does not allow for simulating within the web environment, or use only simple animation without a possibility to vary the parameters such as “Process Capability Index – Cpk vs. Cpk Visual Animation” [5].

The global objective of the paper is to introduce a new Statistical Process Control educational technology using an interactive control charts simulator. The starting point is our experiences in teaching Industrial Engineering and Quality Engineering and Management at higher education institutions. We observed that it is especially that regular students often lack practical knowledge about the production process while managers lack deeper insight into the SPC theory. Both students and officers of varying organizational levels often encounter problems when trying to understand the arduous SPC issue.

A possibility to eliminate the above-mentioned deficiency is a practical activity. “Learning by doing” is the process within which individuals attain knowledge and skills through personal or hands-on experiences [6]. Learning by doing can be costly, the more so the more complex the systems involved is [7]. Therefore simulation is used to make training cheaper.

Any knowledge with high probability of being successfully implemented is mostly attained either through personal experience or with the use of simulations, simulators and other visual aids, already well established in education. Well designed virtual environment can be self explanatory even without an intricate description. Moreover, it supports accelerated understanding and storing-up of the theme discussed through clearness of the situation and via practical engagement in the activity.

Partial objectives of the present paper are described as follows:

- SPC principles and concepts;
- Learning in SPC (tuition and training);
- Setting of learning objectives;
- Simulator tool concept and its functions;
- Usage in the process of education (tuition and training);
- Summary and future development of simulator.

II. SPC PRINCIPLES AND CONCEPTS

Every production, service, or administrative process contains a certain amount of variability due to the presence of a large number of causes. The observed results from a process are, as a result, not constant. Studying this variability to gain an understanding of its characteristics provides a basis for taking action on a process [8].
Statistical Process Control presents a collection of tools (primarily statistical) that help to understand what is going on in processes. SPC is based on the theoretical assumption that the controlled quality characteristic is normally distributed or the controlled discrete characteristic follows binomial or Poisson distribution. The SPC’s basic tool is the control chart that graphically presents the process data and renders a visual estimate of the process variability.

Method of using the control chart:

- At defined intervals, subgroups of items of a specified size are obtained from the process and the value of a quality characteristic or feature of the items is measured.
- Selected statistical characteristics are calculated from the measurements. The difference in values of statistical characteristics presents fluctuations in the process factors in time.
- The decision for a control intervention is based on comparing values of statistical characteristics against the control limits.

SPC has the possibility to be widely used not only in industry but also in agriculture, building industry and even in services. Successful applications are known in banking, healthcare, public administration, and education.

**Process of introducing SPC [9]**

Preparatory phase – to detect statistical process stability, and to determine:

- Stability of the mean of controlled quality characteristic in the course of time;
- Stability of the variability of controlled quality characteristic in time, and determines technical stability, i.e. the ability to keep the tolerance limits.

Stage one – gathering the collection of organizational and technical measures that ensure statistical and technical stability.

Stage two – performing prevention to eliminate the process stability failures based on assessing selected statistical characteristic against control limits.

**III. Learning in SPC (Tuition and Training)**

Learning of the Statistical Process Control (tuition and training) is accomplished within university training but it is necessary also for R&D practitioners, production or service operators, technicians, administrators, process engineers, managers and others. Statistical Process Control training does not need to be difficult, even for people new to the principles of SPC [3].

We developed Educational web Tool for Statistical Process Control (SPCSim) which is a special-purpose learning tool for SPC. This tool simulates real-life processes in web environment and guides students step-by-step through basic statistical concepts and terminology. The tool is easy for anyone to understand and apply in diverse working environments.

The SPCSim provides a definition of SPC and the reasons for its use in any production. The training includes focus on the power of process control. Examples demonstrate how SPC relates to everyday situations in our personal lives, bringing the subject close to everyday work. Interactive examples prove the statistics behind the process really work. Students will learn new information and understand why SPC is an effective and useful tool in reducing or eliminating defects.

This paper presents learning objectives, the SPC simulator concept, its functions, and the manner of its use in education. SPCSim enables the student to resolve typical situations encountered in SPC: to determine fundamental statistical characteristics of measured parameters, to develop a histogram, to set up a control chart, to calculate its control limits, and to continuously monitor the chosen characteristics. Once the characteristics fall out off the control limits it is necessary to determine the cause.

Though it is primarily intended for educators, trainers, and students, it can prove highly beneficial for specialists in quality management systems in industry. Simulation not only significantly enhances learning but it also reduces the cost of training and production design cost as well [10], [11].

**IV. Learning Objectives**

Objective of the SPCSim is seen in allowing the student to attain knowledge, skills and foresight at designing, realizing, and presenting SPC results.

As it was already mentioned, the student should be able to find out statistical features of measured quality characteristics and to develop a histogram. Still further, he or she should be able to set up a control chart, to calculate its control limits and to continuously monitor selected statistical characteristics. Once the characteristic fall out off the control limits, he or she should determine the cause [12].

Out of the above outlined situations the learning objectives result which are expected to be met by employing the SPCSim:

1) To grasp the fact that monitored parameters of a process are random variables that can be observed using statistical characteristics and a histogram.

2) To understand the way how the control chart works, as well as the fact that exceeding of the control limits does not necessarily mean that the process is out of control. An unstable process, on the other hand, produces significantly higher number of “control limits exceeded” signals though absence of such a signal can be occasionally experienced as well.

3) To be able to determine limits of control charts so that the chart has desired properties.

The simulator and the associated user interface were designed so that they would meet learning objectives outlined above. Presented below is a list of those tasks and associated instructions that guide the work of the student:

**A. Learning objective: To understand the fact that monitored parameters of a process are random variables.**

Task: Production process monitoring.
Instructions:

- Run the process with the pre-set parameters.
- Observe the process characteristics (mean value, standard deviation, number of nonconforming products and the histogram) when the process is stable.
- Modify the process parameters and monitor altered characteristics.

B. Learning objective: To understand how the control chart works.

Task: Observing the behavior of Control Charts.

Instructions:

- Observe how control charts work when the process is in control.
- Modify the process parameters and observe functioning of control charts when the process is unstable.
- Determine probabilities of false and missing signals for each case.

C. Learning objective: To be able to determine limits of control charts.

Task: Calculation of control chart parameters.

Instructions:

- Select the unknown process parameters and run the process.
- Based on the measured data calculate the control chart parameters (control limits, central line).
- Observe functioning of charts and determine probabilities of false and missing signals for the case of both stable and unstable process.

A part of the learning process is a feedback in the form of questions that the student is to answer upon completion of each task. Through correct answers s/he will learn if s/he proceeded correctly. Further parts of the simulator are a glossary and textbook covering pieces of theoretical knowledge necessary to master the tasks. The simulator can be used from self learning and distance web based learning up to face to face and collaborative learning.

V. SPCSim Tool Concept and its Principal Functions

SPCSim is a web site set up using HTML, JavaScript and Cascading Style Sheets (CSS). It opens in a web browser either from the computer’s local disc or from the Internet. The simulator structure reflects the learning objectives defined in the preceding chapter and is presented in Fig. 1.

The Home page provides basic information on purpose of the simulator (Fig. 2). The Production Process page illustrates a production process. The process can be started, its parameters altered (mean and standard deviation), statistical characteristics monitored and shown in the histogram (Fig. 3).
The Control Charts page presents Xbar and R control charts. It allows continuously monitoring the data with respect to control limits, recording the number of cases beyond limits, and it allows the user to alter the control limits (Fig. 4). After each change a new line in the charts statistics table is displayed so that behavior of control charts can be compared prior to and after change.

**Figure 4. The Control Charts page.**

VI. USAGE IN THE PROCESS OF EDUCATION

SPCSim is presented to students after introduction of basic terminology and concepts of SPC and control charts. Work with SPCSim further develops understanding of these concepts. It can be used to visually demonstrate a meaning of the terms.

When SPCSim is in classroom setting measured results and any issues of dispute can be resolved immediately. In a self study setting precise instructions, glossaries and pre-prepared answers to questions are at hand.

Once a simulation is launched the tables and charts data are continuously updated. Data can be copied and pasted into another application such as Excel. If the student has mastered the basic theory then all tasks and assignments can be accomplished in 20 – 40 minutes.

VII. SUMMARY AND FURTHER DEVELOPMENT OF SPCSim

SPCSim allows one to monitor the way control diagrams identify the production process instability and, through experimenting, to investigate properties of control charts. These practical activities result in deeper and unforced understanding of the issue.

SPCSim presents to the student real-life practical situations where measurements are performed continuously and where the volume of data grows continuously as well. Simultaneously, calculated statistical characteristics and the production process histogram change continuously too. Experimenting with the process parameters it is possible to observe relationship between rejects percentage and the process statistical characteristics. Further changing process parameters by specific value allows to observe how often control charts generate out-of-control signal. The latter possibilities may be interesting mainly for professionals who can relatively quickly arrive to a finer sense how to implement control charts.

Future development of SPCSim can be seen in the following directions:

- Extending interactivity by implementing a variety of control chart types and production processes from various industries.
- Extending number of tasks, e.g. task to select an appropriate control chart for a given process.
- Process capability assessment, e.g. according to [13], [14], [15].
- Support of the collaborative learning, when groups of students will be mutually developing unknown problematic situations that needed to be resolved.
- Integration into e-learning environment, e.g. according to [16], [17].
ACKNOWLEDGMENT

Incorporated in the article are interim results of the Slovak republic Ministry of Education Project KEGA 009-4/2011: Creative laboratory tuition at technical faculties (CRELABTE), Project VEGA 1/0006/10: Aplikácia metód umelej inteligencie v riadení priemyselných systémov (Application of artificial intelligence methods in control of industrial systems), Project “Centrum excelentnosti integrovaného výskumu a využitia progresívnych materiálov a technológií v oblasti automobilovej elektroniky” (Centre of Excellence in Integrated Research and Utilisation of Top-Notch Materials and Technologies in the Field of Automobile electronics), ITMS 26220120055 co-financed from EU funds.

REFERENCES