ACTIVE LEARNING OF STATISTICAL QUALITY CONTROL IN PRACTICE WITH HOPE-ADD-INN

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The author has developed various kinds of active learning materials creatively for statistical quality control and quality optimization supported by JMP (multilingual version statistical software developed by SAS) to teach engineers and students ranging from beginners to experts ingeniously in order not only to understand statistical methods but also to utilize them actively. This paper illustrates how to achieve this objective by utilizing various teaching materials and design of experiments by appropriate multilevel education according to the level of engineers and students. "QC" (Quality Control) is used in this paper, however, this word may be expressed with "QM" (Quality Management) recently. Similarly, "SQC" used in this paper may be expressed with "SQM". The virtual practical experience which uses virtual reality system is the subject of future statistical education. It will be introduced at the last of presentation by computer demonstration.

PARADIGM SHIFT IN LEARNING STATISTICA QUALITY CONTROL

Training is to inculcate somebody to learn "how" to properly implement a given method by having him/her repeat using the method again and again. In training, why such method is employed or why the method is desirable is not explained. Adherence to the given method is important, and adherence itself is the purpose of training. It is, therefore, forbidden to change the method voluntarily in training, and if a given method is changed, it would be judged as a violation or deviation. It is apparent from the above that maintenance requires training.

Meanwhile, education has two aspects: one is to teach (inculcate), which involves explaining properly not only "How" but also the reason "Why". In-depth understanding of "How" and "Why" often leads to improvement of the given method. Improvement involves enhancing QCD (Quality, Cost and Delivery) by changing methods. It should be noted that there is always some room for improvement in any given method. When improvement goes successful, things will go uphill, and the people concerned will enhance their "ability of problem solving". Training, which does not include improvement within its scope, does not bring about such an advantage. Whether or not improvement can be made divides between training and education. Teach generates future leader.

The other aspect of education is cultivation, in which the background of the product being manufactured, such as needs and seeds which brought the product into existence, essential values of the product, etc., along with the mechanism of current method of production, is explained. This arouses spirit of study in the students, leading them to propose new products (propose what to produce) when they grow. This may also lead them to come up with totally innovative methods (propose what to do). These proposals are what can be called work of creation and serve as proof of their growth. Incidentally, proposals not leading to development (conceiving new ideas and materializing them) are just pies in the sky, and therefore, the word "development" will be used as a keyword. It should be remembered that, since development requires trial and error process, support (watching, advice, and help) is necessary after education. For development, both the spirit of study of students and support provided by the educator are indispensable. The fruit of this is nurturing of "*ability of task achieving*." Cultivation generates future manager.

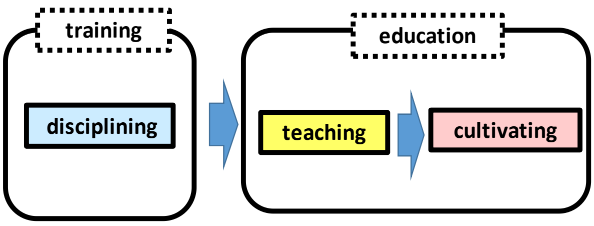

Fig. 1 Paradigm shift from training to education

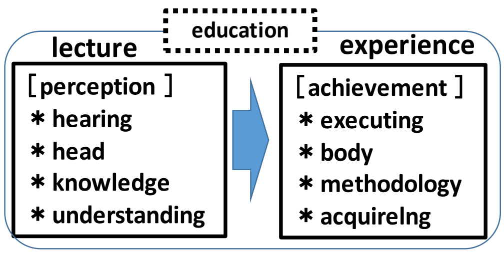

Fig. 2 paradigm shift from lecture to experience

In M. A. Sorto, A. White, & L. Guyot (Eds.), *Looking back, looking forward. Proceedings of the Tenth International Conference on Teaching Statistics (ICOTS10, July, 2018), Kyoto, Japan.* Voorburg, The Netherlands: International Statistical Institute. iase-web.org

PARADIGM SHIFT FROM LECTURE TO EXPERIENCE

There are two styles of education, i.e. classroom style lectures (only comprehension without practical experience) and experience (practical experience besides comprehension), as shown in Fig. 2. Although lectures may lead to good understanding, understanding alone does not help one to work well. It is necessary to give opportunity to students for putting what they understand into practice, so that they may be able to work. In the classroom, not on the shop floor, however, preparation of good teaching materials and well thought-out curriculum are required for successful education, for satisfying the following conditions.

* Easy to understand
* Implementable easily within limited time
* Assures less cost and safe implementation
* Allows the whole project to be mastered in a comprehensive manner

This paper presents the theory of education by simulated experience, in which the above points are taken into consideration, explains its actual content, and discusses important points of implementation.

EDUCATION BY SIMULATED EXPERIENCE USING "MODELS"

QC (Quality Control) being a management methodology, it inevitably requires the use of certain specific technology for practical education through experience. If difficult specific technology is employed, however, learning that technology itself would take up much time, leaving little time for mastering QC. So what counts heavily here is to utilize "Models". "Model" is a "well-made fake" created by extracting only essential elements of a real thing. In a more technical sense, it is an abstracted form of a real thing.

Abstraction = Extraction + Elimination

Extraction means to extract essential elements.

Elimination means to eliminate trivial elements.

In other words, abstracted model is a convenient and useful alternative used to make it easier to understand and handle a real thing. This "Model" is called "educational material" in this paper. Keys to effective SQC education are: what kind of curriculum is used by preparing what type of educational materials for what purpose of education. For this purpose, superior supporting software for statistical data processing data is essential.

What are shown below in Fig.3, Fig.4, Fig5, and Fig.6 are three educational materials (Models) devised by the author himself: coin-shooting machine; paper glider; and twin-rotor paper helicopter. In case of paper helicopter, there are the single-rotor type and the twin-rotor type. The latter is the original of the author, and it is an assembling type helicopter and it has design factors more than 15.

Content of curriculum taught using them is explained in the next chapter. Author's experience over many years in a number of educational opportunities revealed the following:

* A desirable teaching material for SQC is one that allows the result of its operation to be available in the form of data.
* It is essential for SQC curriculum to include roleplaying which gives students opportunity to experience actual practices in group activities.
* Coin-shooting game is suitable for basic education
* Paper helicopter is more suitable for full-scale education.

Twin-rotor paper helicopter is of the author's own development prepared for the purpose of allowing the use of many variables (from 10 to 20), as well as enabling assembly operation.

* Paper glider is good for developmental education.
* Excellent supporting software is vital for carrying out education in an efficient manner, as well as for ensuring good understanding.

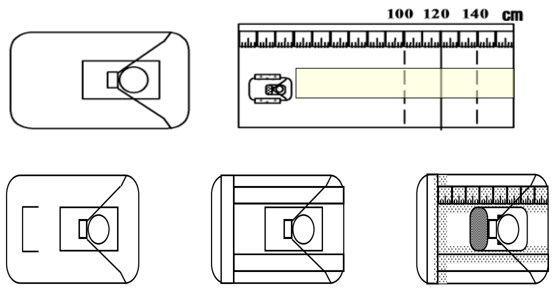

Fig. 3 Coin-shooting machine

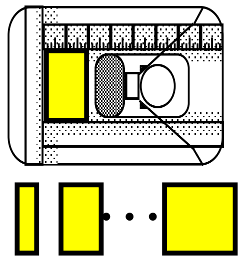
Fig.4 Spacer (useful jig)

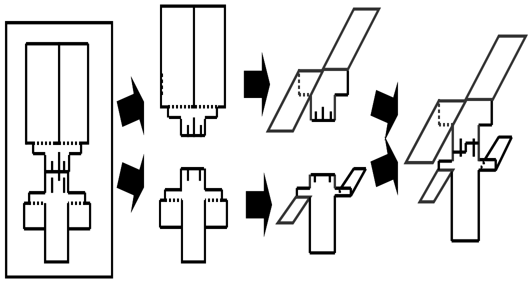
Fig. 5 Twin-rotor paper helicopter which has more than 15 factors

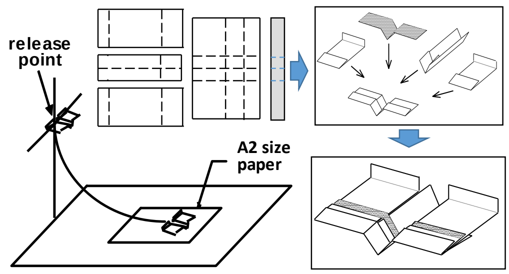

Fig.6 Paper glider

BASIC COURSE USING COIN-SHOOTING GAME

What is shown in Fig. 3 is the coin-shooting machine, which is an educational material easiest to handle and understand. Preparation is also simple, the machine is easy to produce and process, and it allows collecting multiple data in a short period of time. Fig.4 indicates evolutionary process of improvement and development of the shooting machine with useful jig which is spacer.

A shortcoming of coin-shooting game is that the number of variables is limited, and therefore, it is not appropriate for teaching advanced statistical methods such as design of experiment and multiple regression analysis. For such purpose, twin-rotor paper helicopter is more suitable, while for handling more advanced content, paper glider is more adequate.

FULL-SCALE COURSE USING TWIN-ROTOR PAPER HELICOPTER

Reduction of Dispersion and Bias

Breaking up overall dispersion into dispersion by element clarifies areas to be improved. Generally, there are three types of causes leading to dispersion, and the structure of dispersion can be expressed as follows:

$$\sigma_T^2 = \sigma_P^2 + \sigma_O^2 + \sigma_M^2 \quad T: total,\ \ P: production,\ \ O: operation,\ \ M: measurment \qquad (1)$$

Each element of dispersion can be understood by conducting three experiments indicated below and by applying the equation (2).

[1] Experiment 1 (for grasping dispersion V_1):
Produce n number of products, fly each of them and measure the flight duration.

[2] Experiment 2 (for grasping dispersion V_2):
Fly one product for n number of times and measure the flight duration.

[3] Experiment 3 (for grasping dispersion V_3):
Record one flight of one product by VTR and measure the flight duration for n number of times.

Structure of dispersion obtained by the above three experiments will be as follows:

$$\sigma_1^2 = \sigma_P^2 + \sigma_O^2 + \sigma_M^2, \quad \sigma_2^2 = \sigma_O^2 + \sigma_M^2, \quad \sigma_3^2 = \sigma_M^2 \qquad (2)$$

Dispersion can be broken down as shown below using the data obtained from the three types of experiments by using software. Hope-add-inn is an effective supporting software which is easy to use for everybody. After this analysis dispersion can be reduced by targeting at those elements whose coefficient of contribution (ratio of each element to the total dispersion V1) is large.

$$V_T = V_1,\ V_P = V_1 - V_2,\ V_O = V_2 - V_3,\ V_M = V_3 \quad \rightarrow \quad V_P / V_1,\ V_O / V_1,\ V_M / V_1 \qquad (3)$$

Reduction of Bias

What needs to be addressed after reduction of dispersion is that of bias (difference between target and average). This can be achieved by utilizing regression analysis. What needs to be done is to represent the relationship between design factors and characteristics (output) in equation of regression, and then to bring the average closer to the target. While this can be done by producing equation of regression for the length of the wing alone for beginner. It is more desirable to employ multiple regression equation by increasing the number of design factors for expert.

Four Basic Tasks

Four basic tasks in SQC education are shown below. This is an example of paper helicopter, but the same approach is also applicable to paper glider.

[1] Measurement control: Collect reliable data.

Having devises a good way of measurement, three persons take measurement, and use the median.

[2] Problem-solving (improvement; Kaizen): Solve the problem by comparison by stratification.

Pursue causes of outliers and histogram with twin peaks, work out and implement countermeasures, to make it to form normal distribution.

[3] Reduction of dispersion (improvement; Kaizen): Reduce dispersion and control.

Break down dispersion, improve on a factor with major coefficient of contribution rate, and reduce dispersion.

[4] Average control (development): Match average with a target by one or more design factors.Find conditions which can achieve the target using regression equation and reduce bias.

With paper glider, position of the glider is measured after landing following its flight, and therefore, there is no issue about measurement. However, the median of the three times flight data is effective. Because the glider flight varies under the influence of an indoor air current in this case.

DEVELOPMENT COURSE USING PAPER GLIDER AND PAPER HELICOPTER

The main topic in this chapter is development of new products and new production methods. Where phases change because of changes in customer's requirements, improvement alone may not be able to cope with the situation. Giving this type of experience is significant in education.

Case of Paper Glider

Major change occurs when a phase changes, in which case training is not enough to handle. It is not rare that the best thing achieved by training in the past phase becomes the worst one in the next phase. For education on changes in phases, paper glider is appropriate. A case in point is where customer demands longer and longer flight distance. To satisfy this demand, larger paper glider will be necessary, requiring significant changes in manufacturing method. This situation is delineated in Fig. 7 (1), (2), (3), and (4).

(1) Compact type: Everything will work fine if paper is folded firmly until it has strong folding line.

(2) Medium size type: If paper is folded to have folding line, it will result in less strength affecting flight distance, and therefore, folding line must be forbidden. The best in (1) is the worst in (2).

(3) Large type: Even without firm folding line, wings cannot maintain level and expected flight distance cannot be achieved. The body should be reinforced by putting staples into three key points shown in Fig.7(3). With this method, firm folding line is acceptable and it is effective

(4) Super large type: Even staples do not help wings to maintain level. Instead, a stabilizer is fitted as shown in Fig. 7 (4). In this case, the key is to find a simple, easy to handle, and inexpensive stabilizer. [Hints] thin-diameter wire, thin-and-long cut cardboard, half cut drinking straw, etc.

So far as students have good understanding that they are allowed to change the current manufacturing method, as well as on the relationship between the mechanism of the product functions and the current manufacturing method, they will come to be able to cope well with changes in phases. It should be noted, however, that to achieve this, subsequent support, in terms of watching, advice, and help, will be indispensable.

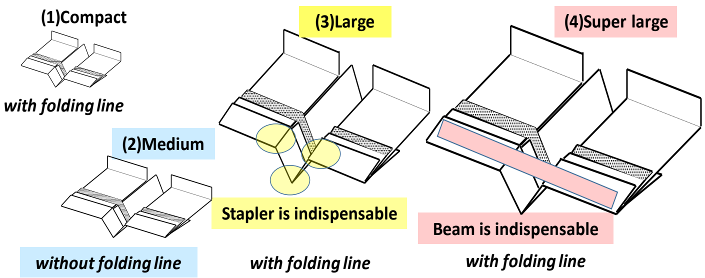

Fig.7 Phase change in glider

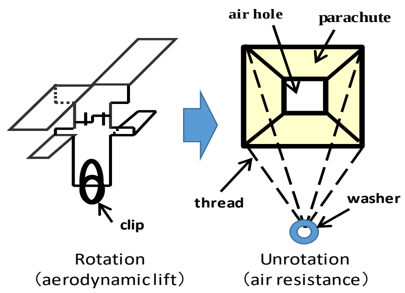

Fig.8 From helicopter to parachute

Case of Paper Helicopter

Essence of customer demand for paper helicopter is for it to “fly from a certain point in air towards floor in required time.”

The essence of customer’s new demand must be achieved without rotation, which means that a new product different from conventional one should be developed. And the new product requires development of new production method.

A good example of a new product in this case is paper parachute. When it comes to moving on to the production of paper parachute, whatever learned in the training of paper helicopter will not be useful. Knowledge acquired through education, however, will be still effective after starting to work on paper parachute, enable improvement in days/months to come, and help development of next projects in future.

QUALITY CREATION BY DESIGN

Goal of SQC is quality creation by design using many factors. Since essence of design is optimization, however, supporting software is essential. The author, jointly with SAS Institute Japan, has developed a supporting software called HOPE-add-in which runs on JMP. Use of this tool enables anyone to carry out sophisticated design with ease. Although its details and screenshots are not given in this paper, they will be introduced in the hall on the day of conference.

The twin-rotor paper helicopter has more than 15 factors, however, single-rotor paper helicopter which has not so many design factors is used daringly here for an easy explanation. There are ten (6+4) design factors in Fig. 9. With regard to the desirable function of time, data should be collected by orthogonal experiment, and modelled by regression analysis. If the range of level is small in single-rotor type and twin-rotor type, interactions can be ignored, and in such a case, it is suggested to adopt the design of experiment in which L12 (up to 11th factor) is used, whereas if the range of level is large, L16 (5 factors) is suggested for interactions. If the range of level is super large, Central Composite Design (3,4 factors) is suggested for second order terms.

Many functions can be made from 6 design factors depending on various design purpose, however, 4 functions described below are prepared for typical and easy optimization example here.

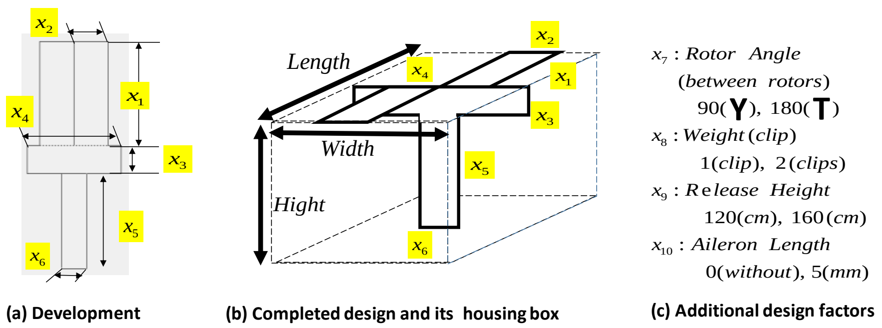

Fig.9 Single rotor type (the range of level is small: interactions are ignored for beginner)

Time : $y = f(x_1,\cdots,x_6) = c_0 + \sum_{i=1}^{6} c_i x_i$ (4)

Area : $S = f_S(x_1,\cdots,x_6) = 2x_1x_2 + x_3x_4 + x_5x_6$ (5)

Gap： $G = f_G(x_2, x_4) = 2x_2 - x_4$ (6)

Volume： $V = f_V(x_1, \cdots, x_6) = 2x_1 \times Max\{2x_2, x_4\} \times (x_3 + x_5)$ (7)

Sometimes functions may result in a highly hierarchical composite function. The use of the support software HOPE-add-in, however, enables highly sophisticated design with great ease. In education of design, teaching in phases is crucial. For example, at the first phase, design is taught only with customer demand (function of time); next, materials cost (function of area) is additionally taken into account for design; then, man-hour (function of gap) is added; followed by addition of storage cost and transportation cost (functions of volume) in design. By raising the level of design progressively, students can experience more comprehensive design.

Once design objective is defined and functions necessary for the objective are made ready, the rest can be handled easily with supporting software for formulation and solution finding. What is important in SQC education curriculum is to let students experience comprehensive design with diverse perspectives in phases as described above.

An example of relatively high-level design which uses mathematical programing is introduced below. The design scenario has following three constraints

(1) to satisfy customer requested C_{CR} time ($y = C_{CR}$),

(2) to have shape easy for production with no gaps (G=0),

(3) to satisfy the condition of volume to be less than C_V for reasonable storing ($V \leqq C_V$), and following objective function

(4) to minimize the area of helicopter S for total economic rationality (S→minimize).

What follows is the formulation for solution finding.

$$\begin{aligned} &\textit{Objective function}: S = f_S(x_1, \cdots, x_6) \to \textit{Minimize} \\ &\textit{Constrains}: y = f(x_1, \cdots, x_6) = C_{CR},\ G = f_G(x_2, x_4) = 0,\ V = f_V(x_1, \cdots, x_6) \le C_V \end{aligned} \quad (8)$$

Use of supporting software allows even beginners to prepare various required functions, as well as optimization based on them. Hope-add-inn is an effective supporting software which is easy to use.

CONCLUSION

This paper discusses paradigm shift in SQC education. In a broad sense, it is a shift from training to education, and in education, it is a shift from lecture to experience (role-playing). Although training is essential as a foundation for SQC education, it should not stay there but to move on to education. An important point about education is not to be bound by inculcating (simply sharing knowledge), but should go on to nurture (cultivate and let students grow). While lecture is indispensable to get knowledge, however, it would be nothing but “pie in the sky” unless methodology and management are mastered through experience (practice of role-playing.)

Carrying out the above requires preparation of good teaching materials and devising effective curriculum. While theory of SQC education is discussed on one hand, this paper also presents specific educational materials and curriculum, and raises important points about implementation. The virtual practical experience which uses virtual reality system is the direction of future statistical education. It is introduced at the last of presentation by computer demonstration.

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