The Process of the Acquisition of Industrial Skills

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本論文は1967年9月ヂユネーブのILO本部国際職業訓練調査センター宛送付せる処ILO人的資源局職業訓練課長H. W. Quednau氏より10月6日付公文を以て本論文をILO発行のCIRF Abstracts中に掲載する旨来翰があつた。

（訳者　注）

Mr. H. W. Quednau, Chief, Vocational Training Branch, Human Resources Department, International Labour Office informed us in his official letter to have the intention to insert this Dr. Naruse's theory in the CIRF Abstracts.

(6th Oct., 1967)

Preface

As part of a project for studying the nature and acquisition of industrial skills I have carried out some experiments and found out the general equation of learning of skill and craft, thus I presented the results of my study as part 1 already before.

This time I have analysed my study and generalized and extended the theory--that is--the general formula of skill acquisition process and gained the conclusion.

Here I present my study as part 2 which is called the generalized and extended formula of the acquisition of industrial skills.

The author is indebted to Mr. P. Y. Uchida, researcher of the Department of Research and Study of the Institute of Vocational Training for an English translation of the manuscript.

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OGAWA, KODAIRA, TOKYO

May, 1967

The Process of the Acquisition of Industrial Skills

— the generalized and extended formula of skill training —

by Dr. Naruse Masao

1. Foreword

Here I define the ability of producing things as skill, and also define the repeated practice to attain a certain skill desired as training. Now skill and training thus being defined, I try to consider about the process in which skill is trained.

2. Training or Learning of Language

Here I use the word 'skill degree' which shows the level of skill, and denote it as y. and try to get the formula of y .

Thinking the quality of language to be similar to skill, I have researched the process in which language is to be promoted by training, and then transfered this process to other general skill, thus I tried to get a formularization of skill. During this trial I set up several suppositions, which are as follows:

(1) The Japanese language spoken by foreigners is not always in the pure form. Some of them are professors in charge of Japanese language or well-known christian missionaries--that is-- the selected people. Those selected people have linguistic genius and ability and have learned Japanese earnestly. In spite of these situations their Japanese language is not always in a pure form.

From this consideration I can easily assume that human ability or enthusiasm does not influence much on learning or training of language.

(2) On the other hand the Japanese language spoken by foreigners who were born and bred in Japan is quite the same with that of Japanese children and is in the pure form. They began to learn Japanese from their childhood and have gained rapid speed in speaking in the pure form.

It is assumed that the younger he starts learning of Japanese, the faster he attains the ability of speaking. These infants do not make serious efforts, nor are influenced by ability or nature, and yet they will be able to speak Japanese in its pure form.

Thus the younger he starts learning language, the faster his ability of speaking is promoted.

(3) Thus considering from training effectiveness, the same

amount of time spent for training is not same in its content. Time spent while one is young has good effect in training, but time spent while he grows old has poor effect.

As for training effect past time can neither be converted into nor be exchanged with future time. Therefore it can be said that in learning of language time can't be converted.

(4) We often meet a person who can speak two or more different national languages. From this case we can say that language has its nature which permits different languages to coexist in it.

(5) Furthermore, the ability to speak language grows with age. For instance, in childhood two years old baby can speak better than one year old baby, and three year old baby does better than two year old baby and so on.

But at a fairly old age the elder can not always speak better than the younger. Hence we come to the conclusion that speaking skill of language attains asymptotic saturation at a certain age.

(6) Comparing a well spoken man with an ordinary person, his speaking ability is comparatively high and sometimes at its highest. It can be considered that even an ordinary person will be able to speak fine to a certain degree if he

cultivates his effort of learning. Thus we can find out tha training of language has its elevation.

(7) Here we consider the case in which two or more differen languages will be learned by training one by one in order. When one starts his lesson of the second language, he may be influenced by the training effect which was already caused b the first language training. That is--some percentage of th first language training effects will give an effective influence to the second language training.

Here I denote this percentage as β which stands for transfer coefficient.

(8) When a man gets fairly old, his speaking ability will l gradually weakened by decrepitude. Here I nominate this trend as 'language decrepitude' and denote the term as R_t (the term decrepitude).

Therefore at a fairly old age, language ability will b retarded, which is caused by R_t . In other words speaking skill is composed of two terms--that is--ascent and descent

3. Here I express language training by the formula mathematically.

I define the ability of well speaking by training as and t for time (or age).

Now we consider the case in which language training is performed ideally, and try to examine the item (2) among those eight items above mentioned. In this item I have pointed out that the speed in which language is promoted--that is-- dy/dt will decrease according to the increase of age t.

Here I express this trend by the formula mathematically as follows:

Here we insert k as proportion constant, then we obtain the following formula:

$$\frac{dy}{dt} = k\frac{1}{t^n} \quad \cdots\cdots (1)$$

transforming equation (1), then we obtain:

$$dy = \frac{k}{t^n}\,dt$$

The integration of the equation above, using C as the integration constant, becomes:

$$y = \int \frac{k}{t^n}\,dt + C = \frac{k}{n-1}\left(-\frac{1}{t^{n-1}}\right) + C \quad \cdots\cdots (2)$$

In order to decide the value of C of this formula we will consider about item (7) before mentioned. That is--when t_0 stands for time to start training, β percent of y_0 which

denotes the well-speaking ability of the first language wil give influence to the second language training. Thus we se the formula as follows: $t = t_o$ $y = \beta y_o$

Here we use these terms as incipient factors of the equation (2).

Substitute these factors in the above formula (2).

$$\beta y_o = \frac{k}{n-1}\left(-\frac{1}{t_o^{n-1}}\right) + C$$

$$\therefore \quad C = \frac{k}{n-1}\left(-\frac{1}{t_o^{n-1}}\right) + \beta y_o \quad \cdots\cdots (3)$$

Substitute this value (3) in formula (2), and we obtai

$$y = \frac{k}{n-1}\left(\frac{1}{t_o^{n-1}} - \frac{1}{t^{n-1}}\right) + \beta y_o \quad \cdots\cdots (4)$$

Thus assuming that the ideal learning of language is performed, notation y which stands for 'speaking well' is indicated by the equation (4) shown above. But in fact tra ing is not always performed ideally. Therefore y_a which denotes well-speaking ability in actual training is assumed to be α percent of y_a. Then we obtain

$$y_a = \alpha y \quad \cdots\cdots (5)$$

Substitute formula (4) in formula (5), then

$$y_a = \frac{\alpha k}{n-1}\left(\frac{1}{t_o^{n-1}} - \frac{1}{t^{n-1}}\right) + \alpha\beta y_o \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (6)$$

Here we examine each item which was explained in article 2 before mentioned.

As for item (1) in article 2, considering formula (6), it does not include any value which relates to individual nature or ability. Therefore formula (6) has no relation to human quality or ability. Thus item (1) is satisfied in formula (6).

As for item (2) in article 2, in formula (6), when t_o is small, then y_a is large, and when t_o is large, then y_a is small. This fact satisfies item (2) in article 2.

As for item (3) in formula (6) t is a function of t_o notation t which has different values of t_o is not the same in value. That is-- t has different values when t_o is different, therefore t has no conversion. Thus formula (6) satisfies item (3).

As for item (4), formula (6) does not mention any co-existence of languages. In other words formula (6) does not deny the coexistence of languages.

As for item (5), if $t = \infty$ in formula (6) we obtain

the following formula:

$$y_a = \frac{\alpha k}{n-1}\left(\frac{1}{t_a^{n-1}}\right) + \alpha\beta y_o = \text{constant}$$

Therefore formula (6) satisfies asymptotic saturation.

As for item (6) α in formula (6) is the value of percentage. The value of α is 1 for an ideal case. The value of y_a will increase step by step according to the increase of α . When α becomes maximum 1, then y_a becomes maximum value which is y . Furthermore, y_a will be also changed according to the value of n .

Here we may consider n to be the value which will give pressure upon well-speaking ability. When value of n will be diminished, the pressure will be decreased. Therefore when n is small the value of y_a can be increased, too.

Thus the value of α is enlarged and the value of n is diminished, then y_a will obtain more and more large value. Therefore formula (6) satisfies item (6).

As for item (7), in formula (6) it contents term which has the value β in the second term. Thus the formula (6) satisfies item (7).

In item (8) we already explaned that language has a tendency of decrepitude. Formula (6) does not relate to this

decrepitude. The formula does only explain that language will be gradually promoted by training and will finally reach the maximum of saturation at which the promotion is limited. But it does not relate to the descent after the saturation. Therefore, adding the descent value R_t of skill y_a caused by decrepitude to the formula (6), we try to obtain the formula of skill training from formula (6), then the result is:

$$y_a = \frac{\alpha k}{n-1}\left(\frac{1}{t_a^{n-1}} - \frac{1}{t^{n-1}}\right) + \alpha\beta y_a - R_t \quad \cdots\cdots\cdots\cdots \quad (7)$$

This is the general equation which will show the well-speaking ability by training--that is--the skill level of speaking language.

4. Training Formula in S pecial Case

(1) The training formula which is applied to those who will just start learning of language can be obtained in the general equation (7) when "$y_a = 0$" is induced. Thus it follows:

$$y_a = \frac{\alpha k}{n-1}\left(\frac{1}{t_a^{n-1}} - \frac{1}{t^{n-1}}\right) - R_t \quad \cdots\cdots\cdots\cdots \quad (8)$$

(2) Here if we observe only the training for younger trainee we need not consider about the decrepitude term R_a, thus we obtain the following formula:

$$y_a = \frac{\alpha k}{n-1}\left(\frac{1}{t_a^{n-1}} - \frac{1}{t^{n-1}}\right) \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (9)$$

In this formula we take y_a as the ordinate and t as abscrissa, and indicate it as a graph in Fig. 1 as follows:

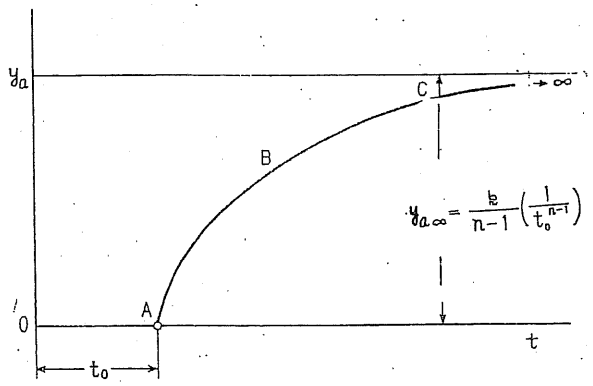

Fig. 1 The training formula (9) while one is young

In this graph we take OA as the value of t_0, and t as . And if y_a is $y_{a\infty}$, then the value $y_{a\infty} = \frac{k}{n-1}\left(\frac{1}{t_a^{n-1}}\right)$ by formula (9). Therefore the desired curve of formula (9) starts from point A and indicates the curve ABC which is asymptotic for $y_{a\infty}$.

5. The General Equation of Language Training and its Relation with other Skill Training

Those general equations (7), (8) and (9) are the training formulas concerning skill, and they are all certified by the experiments shown below. These formulas can also be applied to other skills. The possibility of application can be judged by the following experiment.

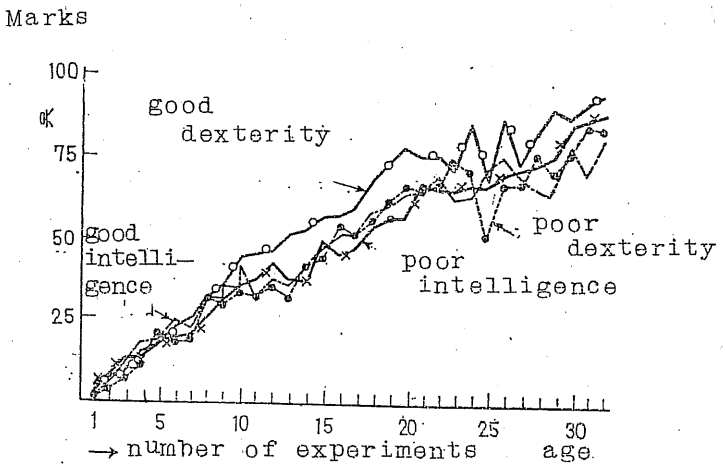

Fig. 2 Experiment (1)
Skill Acquisition Curve by Both Hands Coordination

Experiment (1) shows the result of the test in which how the marks of skill acquisition by both hands coordination were gained in upward trends according to the number of tests performed.

12 subjects were selected among the trainees of the Comprehensive Vocational Training Center attached to the

Institute of Vocational Training here. (in Tokyo) Those marks in the experiment are the averages which were attained by the 12 trainees.

In Fig. 2 the expression 'good intelligence' means the value which was gained by the good group of aptitude under the test by GATB (General Aptitude Test Batteries) No. 2 compiled by Ministry of Labor of Japanese Government. And the expression 'poor intelligence' (indicated in Fig. 2) means the value gained by the poor group of aptitude. The other expression 'good dexterity' means the value which was gained by the good group of finger dexterity and of manual dexterit who were judged to be over standard level. On the contrary the expression 'poor dexterity' means the value of the poor group who were under the standard level.

It is remarkable to find out that the two experimental curves which show good intelligence and poor intelligence have almost no difference between them.

Experiment (2) in Fig. 3

The experiment shows the result of skill acquisition process by FDB (Finger Dexterity Board) operation. Fig. 3 shows the above result.

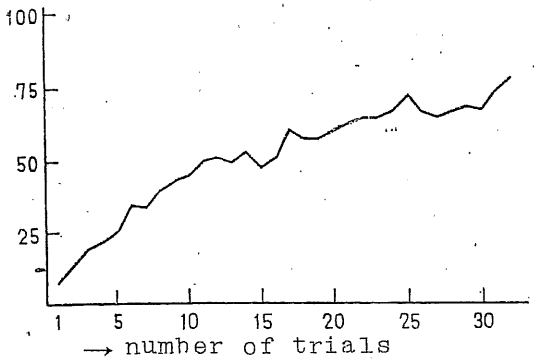

Fig. 3 Experiment (2)
Skill acquisition curve
by FDB operation

As the result of these experiments the shapes of each curve are seemed to be similar to the shape of the curve in Fig. 1.

Thus we can admit that the language training formula (9) can be applied not only to language but also to other skill training.

Then we had an experiment on decrepitude trend. We picked up 399 subjects through the whole country, and measured the value of R of these people under the test by GATB No. 2 compiled by Ministry of Labour. And the result of the test is shown in Fig. 4.

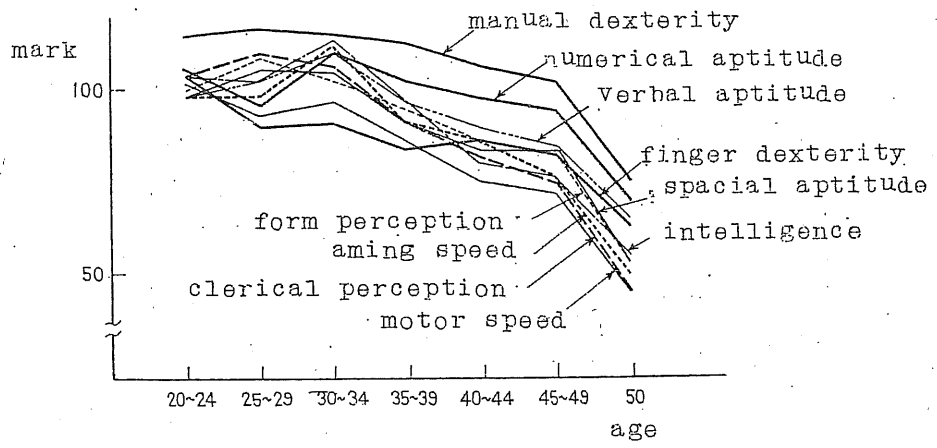

Fig. 4 The curve shows the value R_t of decrepitude

Thus we know that the trend of decrepitude will begin to appear at the latter half of age 30, and will be deteriorated step by step according to t (that is time or age).

Among 10 kinds of ability in this experiment verbal aptitude is also included. Degenerative trend of verbal aptitude according to age t is similar to that of other aptitudes. Thus we can say here that it is adequate to analogize other abilities by verbal aptitude.

By those experiments mentioned above, we know that language training is similar to other skill trainings. Thus we can admit that the formula (7),((8) and (9) obtained before can be applied not only to language training but also to other skill trainings. Among these formulas formula (7) is a general equation, then this general equation can be

applied to skill training.

Therefore those notations which are contained in these formulas can be meant as follows:

y_a = value which indicates skill dexterity

k = constant decided by variety of skill to be trained

α = trainees effort or enthusiasm while he is in training, or instructor's dexterity or enthusiasm while he is in instruction

n = value which degenerates training effects or bad surroundings

t_0 = age or time when training is open

t = age or time for training

β = transfer coefficient in training

R_t = value of skill degenerated by decrepitude

Thus being defined, the general equation of skill training is now to be indicated as follows:

$$y_a = \frac{\alpha k}{n-1}\left(\frac{1}{t_0^{n-1}} - \frac{1}{t^{n-1}}\right) + \alpha\beta y_0 - R_t \quad \cdots\cdots\cdots\cdots \quad (7)$$

Now we pick up only the first term of formula (7) as No. 1 in special case, and apply it to skill with which a young trainee will continue his only one training, without making any change in his training process. This process is formula (9) indicated before. This formula will ascend as

time goes on.

$$y_2 = \frac{\alpha k}{n-1}\left(\frac{1}{t_0^{n-1}} - \frac{1}{t^{n-1}}\right) \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (9)$$

Now we omit the second term only from formula (7) as No. 2 in special case and apply the formula without the 2nd term to skill with which a trainee will continue and devote to only one training until he becomes old, without making any change of training. This is formula (8) mentioned before.

Now as No. 3 in special case we consider the formula in which every term of the formula (7) is included. The first term of this formula is a term of promoted training which shows that skill will always be promoted as time goes on. ' $\alpha\beta y_0$ '--the 2nd term of formula (7) is the term of training for job-changers which will appear in the process of changing of training. The 3rd term is the decrepitude term caused by being infirm with age which shows descent of skill.

Therefore the total of these three terms is the general whole which combines ascent and descent of skill together. Thus this is the general equation of skill training which can be applied to all period of training for job-changers, the youth, the adult and for the old.

6. The Process of Skill Training

Here we consider the process of skill training. As for the general equation of skill training mentioned in the above article, we better understand it if we follow up the curves of the formula. At first we consider formula (9). As for t_0, we set t_0 as abscissa. And we set a constant as α, n and k. Then the formula (9) can be shown as the curve ABC in Fig. 5. This curve, when $t=\infty$, will have the following constant value.

$$y_a = \frac{\alpha k}{n-1} \frac{1}{t_0^{n-1}} = y_a\infty = \text{constant}$$

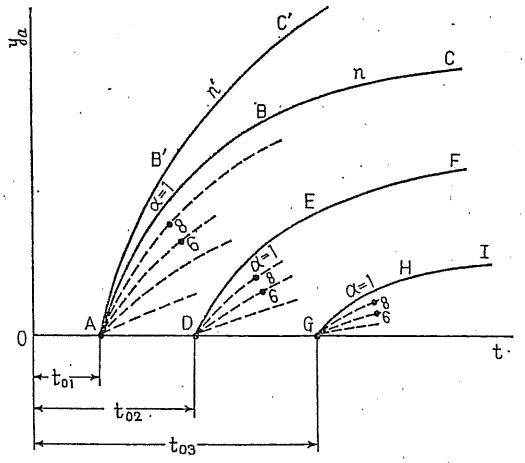

Fig. 5 The Process of Skill Training
— in case of trainee who is young and with no job-change —

Here we take t_{o2} which is bigger than t_{o1} as the value of t. Then the curve will be shown as the curve DEF in the figure. The curve DEF is under the curve ABC which was already shown before. Then we take t_{o3} -the more bigger value than t_{o2}, then it is shown as the curve GHI. Thus we can say that the smaller the value of t_o is, the bigger the value y_a of skill is.

Now we take several values from 0 to 1 as value α. Then those curves will start from each point such as point A, D and G, as they are shown in Fig. 5.

We change the value n --that is--we make n smaller, and get n'. Then the curve of y_a is shown as the curve AB'C', which comes over the curve ABC. When we make the value n bigger, then the curve of y_a comes under the curve ABC.

Now we follow up the curve of the formula (8) and consider about decrepitude trend. Here we have R_t as the 2n term. This R_t will give influence upon the process of skill Refering to Fig. 4, we get one curve which is the average curve of R_t among several curves in the figure, and indicat it as the curve PQ in Fig. 6.

As the 1st term of formula (8) is the same with formula (9), so its curve is the same with that of Fig. 5. Thus we draw the same curves in Fig. 6 with those of Fig. 5. That

is--we draw these curves as ABC, DEF and GHI in Fig. 6.

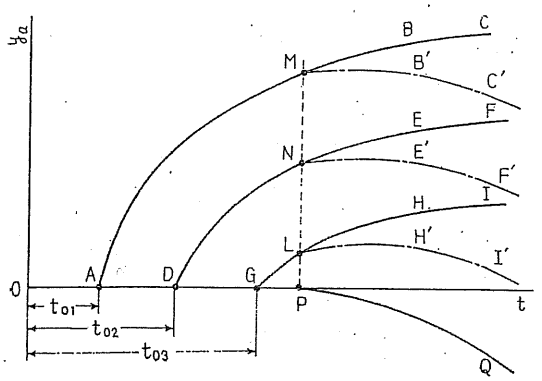

Fig. 6 The Process of Skill Training for trainee from his youth to his decrepitude without changing his jobs

Now the 1st term of formula (8) shows that the value y_a will rise up (or ascend) by skill training. The 2nd term shows that the value will begin to descend at a certain age because of decrepitude. Therefore the formula (8) indicates that these comprehensive effects are in fact the value of skill y_a .

Therefore the value of y_a is shown in those curves such as AMB'C', DNE'F' or GLH'I', each of which is gained from those ordinate values such as curve ABC, DEF or GHI which are reduced for each by the ordinate value of PQ.

By these curves we can observe the process of skill training for trainees who are trained from youth to

decrepitude, without changint their jobs.

Now we consider to add the transfer coefficient term βy_0 to the formula--that is--we follow up the curves in formula (7) as the case of training for job-changers. He we consider the case in Fig. 7.

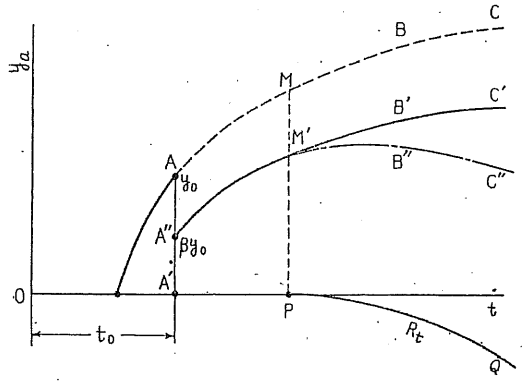

Fig. 7 Training Process in which transfer term β is to be considered--that is--the case of training for job-changers

Here we take the curve of skill where the value of first skill y_a gets the level in which $y_0 = AA'$ when the a t_0.

In this case, if the trainee will continue the same training, it will trend the curve ABC which is shown in dotted line in the figure.

Suppose we change here the pattern of skill trainir and the value y_a of the skill just before the change of

pattern is shown by notation AA' in the figure and this is equal to y_o .

Suppose the value y_o is increased by the following training and gets 50% of useful effect, then the transfer coefficient β is 0.5. Thus the next skill training will start at point A" which is the middle between A and A' and trend along the curve A"B'C' in the figure (7).

Finally when $t = \infty$, the formula (7) will be as follows:

$$y_o\infty = \frac{\alpha k}{n-1}\left(\frac{1}{t_o^{n-1}}\right) + \alpha\beta y_o - R_t$$

The curve A"B'C' will be influenced by decrepitude trend R_t during the process of training. The value of R_t is shown by PQ in the figure (7). Therefore the curve A"B'C' will begin to fall down of point M' on the curve in the degree due to R_t and follow the descent curve M'B"C" as shown in the figure. Thus when one kind of skill training is given and is transfered later to another in the process, then the value of y_o of that training will generally be smaller than that of the training which would not have been transfered. And the diminishing rate of the value is such that the smaller the smaller the value β is, the smaller the value y_o . How the skill curve will change according to

α , n or t_0 is the same with the curve before mentioned

7. Conclusion

With these observations performed, we can assure the following items concerning the process of skill training. They are as follows:

(1) The general equation of skill training is indicated the formula (7) as mentioned before.

(2) The skill which is cultivated while young--that is--while t_0 is small grows strong. Therefore we had better start training in childhood in order to elevate his level skill.

(3) A man has an ability to attain ' $\alpha = 1$ '. The value would be able to attain the maximum value 1 by such facto as surroundings, instructor's ability, trainee's own effo and enthusiasm. But in general the value α is under 1.

Therefore we can make the value α to approach to 1 serving good surrounding, good instruction, and cultivat trainees to get them efforts and enthusiasm.

It is important for skill training to make the valu to reach maximum 1.

(4) The value of n should be small. In order to make value n small, it is necessary to apply science and

technology to skill under good surroundings and make skill to rise up against time t . Originality will be created by the application of science and technology. Inducing the rapid growing science and technology and applying them to skill and craft, then we can make skill to promote rapidly according to time t . At the same time the value of n will be diminished small and skill training will attain a remarkable result.

(5) As for β , the transfer coefficient β will often have the value under 1. Therefore the training for job-changers is inferior to the training without changing jobs. This will explain job-changing to be undesirable. So we should arrange training for job-changers to be more useful, though it is unfavorable. For this reason it is desirable to make the value β to approach to maximum 1.

Although training for job-changers is unfavorable, it will not always be so if we make β to attain maximum 1 and arrange a good surrounding by our original ideas and induce science and technology to the training, thus making the value of n smaller. Then the training will be possibly better for job-changers than for those who do not change jobs.

(6) Skill training is a repeated practice to produce things, using on's own hands and body. Therefore each of his physical

motion is very important. The physiological function which will handle each motion will be in decrepitude trend at about age 30. And by this infirmity with age training effect will be decreased. Therefore it is urgent to protect against decrepitude by sports or medicine on one hand and start training while young on the other hand, thus elevating training effect to higher level.

昭和43年9月26日発行

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