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Part 4

Education, Feedback, Regulators, Linear and Non-linear Systems

Identification, Differential Games, Discrete and Stochastic Systems

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PART 4

COMMENTARY ON HIGHER EDUCATION IN AUTOMATIC CONTROL

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ABSTRACT

The commentator draws attention to the fact that hardly any scientific study has been made of the process of educating control engineers. Some results of Educational Research are cited to emphasise that many beliefs about higher education are unfounded.
The four papers presented in this session are discussed briefly.
With a view to the limited amount of time available for discussion and the overwhelming many-sidedness of higher education in automatic control, a tentative classification of subjects is suggested for use as a guide to the discussion.
Finally, a bibliography on higher education in automatic control is presented.

HIGHER EDUCATION - A CONVERSION PROCESS

To introduce the subject of this session, let us try to look at it from a control engineer's point of view by discussing a hypothetical example.

For this purpose, suppose that a control engineer is called upon to take part in the design and the control of a chemical conversion process. A process that takes in a stream of raw material consisting of particles having rather widely different properties, and which must deliver a stream of particles which have to satisfy certain, fairly exacting, minimum requirements and are to be further processed elsewhere. How would our control engineer have to go about this task?

Obviously, one of the first things he will have to find out is how the *performance* of this process can be defined by questioning people familiar with it. To give our example a realistic touch, let us assume that he does not get a single clear answer. Instead he gets a host of vague and partially conflicting answers. True, there is one hint of system in the chaos because everybody stresses the point that the product qualities must be maximised while the costs must be minimised (apparently, nobody can do very much about the quantities of feed and product), and everybody seems to feel certain that the product has many different and important properties and potentional applications, and that the costs are many and varied. Furthermore, when confronted with the objection that one can usually not maximise quality and minimise cost simultaneously, those who give in to such kind of logic will grant priority to maximising quality and probably stress the need of putting maximum constraints on the costs. Let us finally suppose that the experts consulted by our control engineer have one other trait in common, which is that not one agrees with the rest about the relative importance of the various product qualities nor about that of the various cost items.

Probably, our control engineer would throw his hands up in exasperation and exclaim "What kind of outfit is this where you can't specify - except in the most general, and vague, and useless ways - what kind of products you are making for what kind of applications and what are the costs, let alone that you can reduce them to the same denomination?!" But by that time he would also begin to realise that *if* anybody *did* come forward with firm answers, these would probably be wrong. Except, of course, if they were based on a solid scientific analysis of the product, or its application requirements, or both. But in our example, these are not available.

What would our control engineer do if he were not permitted to quit? He would probably try to analyse the plant itself, in the hope of stumbling upon some wisdom in that way. In our example, the plant would turn out to consist of hundreds of devices, and while the outer appearance of each device would be quite clear and understandable, very little would be known of the processes taking place inside. Worse still, our control engineer would find that hardly anybody had ever tried to subject those processes to scientific study: attempts to precisely define the processes that are taking place, to measure what is going on, to plan experiments and compare their results, would be virtually non-existent. Instead, there would be a plethora of *opinions* and *speculations*. And of *empirical* experiences: things that happened to happen, although under undefined and uncontrolled circumstances. Our pitiful control engineer would probably lose his temper again and exclaim: "When ever will you be going to replace this mediaeval sort of craftsmanship, based largely on tradition and beliefs, by an approach based on solid scientific study? What kind of process is this anyway??".

The answer might be: *"Higher education of control engineers"*.

2. *THE FUTURE ROLE OF EDUCATIONAL RESEARCH*

When one comes to look at it as we did in the preceding section, the situation is indeed rather absurd. Control engineering is a modern subject that owes its very existence largely to the application of the methods of science. Yet the process of teaching (and learning!) has virtually never been a subject of scientific study. In many cases, control engineering is taught with the most modern educational aids, but scientifically sound evaluations of the effectiveness of these aids have failed to appear. Beliefs and opinions abound; experiment and measurement yet have to replace empiricism.

Certainly, this radically different attitude with respect to the teaching process on the one hand and the subject that is taught on the other, is not restricted to control engineering. In many different places in universities, people are beginning to find out that they know next to nothing - certainly not in an operationally useful sense - about the educational process and its products. In fact, those who try to study the subject in a scientific way seem to be arriving at the conclusion that many of the beliefs so cherished by teachers are either ill-founded or totally unfounded. Let us consider a few - highly condensed - examples, most of which are based on research done in the U.S.A.*

• In discussions about lectures, etc. it is often argued that it is very important to have discussion. Discussion is said to activate the students, to make them participate, thus bringing the subject-matter to life, improving the transfer of knowledge. From this it would follow that formal lecturing is obviously an inferior method of teaching. But comparative experiments have invalidated this belief almost completely; the knowledge acquired was not significantly different in most experiments, and in the few cases that seemed to indicate a not insignificant difference, the score was <u>in favour</u> of formal lecturing *(6)*.

• The above findings are typical; time and again scientifically conducted comparisons of different methods of transferring knowledge reveal that differences in effectiveness are wholly insignificant or at best far less significant than expected by the educators *(3,6)*. Or, to put it more bluntly, if one tests what the student has learned, it does not matter a bit how the subject was taught, in formal lectures or discussion groups or laboratory experiments or project work or any other form.

• To some it may come as an even greater shock that the characteristics of the teacher were found to be of doubtful importance when correlated to the students' achievements *(2)*.

• In our university, mechanical-engineering students were required to work a couple of weeks in a metal-ware factory as untrained workmen before entering upon their second year. The motivation for this was that they would gain first-hand experience of life in industry, and in particular that they would form better-founded opinions about:

- workmen; their world of thinking, their way of life, their behaviour at work,
- the social distance and relations between an engineer and a workman,
- the engineering profession,
- industrial leadership.

The results of testing the students were perplexing: on <u>none</u> of these counts any significant effect of the stay in industry was detected *(5)*.

• There seems to be no end to astonishment when education is submitted to scientific evaluation. Even the effect of tutoring was found to be doubtful. Experiments were conducted - and repeated - with matched pairs of groups of students living under virtually identical conditions, one group of each pair being tutored and the other being left to its own resources. The effect of tutoring, measured in terms of examination results and psychological motivation of the students, was found to be insignificant in most cases and disadvantageous in the remainder *(4,5)*.

Thus, it is to be expected that many beliefs that still seem so secure and patently self-evident, will become the victims of scientific study in the future, especially so if one realises how very little we know about the processes of thinking and learning. Therefore, there is no doubt about it:
The advent of educational research is, at present, by far the most important development on the scene of higher education in general, and hence also on the scene of control engineering education.

3. AIMS OF CONTROL ENGINEERING EDUCATION

One feature of the situation discussed in the preceding sections is that the educational aims are so vaguely defined. In fact, it is not uncommon for a certain educational system to be discussed without any reference whatsoever to the future tasks of the graduate, as if it is self evident that tradition and textbooks determine what should and what should not be done.

What should be self-evident to any control engineer is that the definition of the aims of an educational system is of primary importance. A scientific approach would demand that these aims be catalogued as completely as possible and be defined with sufficient precision, preferably in such a way as to allow the construction of tests. An attempt to compile such a catalogue is obviously beyond the scope of this commentary, but it would certainly be one of the major subjects for the discussion in Session 24 of this Congress. But perhaps that discussion will have to be limited to what should be done to arrive at a better definition of the aims of control-engineering education, for the scope of this subject is so wide that it is hard to grasp. It certainly

* It is remarkable how long ago some important papers in this field were published; and how little of this knowledge seems to have diffused into control-engineering education!

is not just a matter of defining the required knowledge. Other things may be even more important than knowledge, like ability to recognise and define a problem, or to circumvent a problem, skill in selecting and combining knowledge to solve a certain problem and skill in applying that knowledge, abilities to learn, to communicate, to work in a group, to coordinate and lead the work of others, insight, capability to evaluate the results of the work, and the way it was done (improvement of personal habits), creativity, and so on*. All these and many other things determine the effectiveness of an engineer, and the effectiveness of its graduates ought to loom large in the aims of an educational institute.

Before concluding this section, let us add that the necessity of better defining the aims of higher education is steadily increasing. Until a few decades ago, only a small proportion of the population took higher education. Not all of those students were exceptionally gifted, but the future seemed less exacting then than at present, and many of the less gifted students had a secure job waiting for them anyway. Today, many universities have to cope with a growing proportion of an ever-growing population and many educators are inclined to believe that the average ability of the students is declining. Broadly speaking, we can divide the students into three groups: the very gifted, the unsuitable, and the intermediate group. And although the education of the gifted students may be the most gratifying task of a university**, its most essential contribution to society is undoubtedly the preparation of the, relatively large, intermediate group for its future tasks. But it is precisely for these students that the match between education and future tasks is the most critical. Therefore, these tasks must now be analysed more carefully than ever before. Here we have another task in which educational research can be of great help to us.

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* For a more systematic survey, reference is made to Bloom *(1)*.

** For them, a precise analysis of the possible future tasks is less important.

4. HIGHER EDUCATION IN CONTROL ENGINEERING - A CLASSIFICATION

The congress programme allows only a single hour to discuss this vast subject. Experience in the IFAC *Workshop on Higher Education in Automatic Control (Dresden, March 15-18, 1971)* has shown that - even if it is limited to a much more restricted subject, like modelling or computers - the discussion tends to disintegrate, jumping back and forth among a number of subjects that are hardly interrelated. Therefore, the selection of a number of themes is recommended to prevent this kind of time-sharing. To facilitate this, a classification which attempts to cover the various aspects of automatic-control education in a more or less systematic way is presented in the accompanying table. For ease of reference, the various items are numbered.

Many of the points mentioned in this table are worthy of discussion, either individually or in certain combinations. For example, points 1 and 2 have a strong influence on points 6, 7 and 8, whereas the problems in connection with points 3,4 and 5 are largely of an organisational nature, although the methods of teaching and testing (9,10) are also affected.

Let us mention some specific points to ponder. Under *the aims of control-engineering education* (6) ways of learning from our graduates in order to get feedback from practice would be a good subject, as would be the relative importance of scientific originality versus design ability.

The *subject matter* (8) has already been discussed so frequently that it is perhaps better to let it rest, although it might be interesting to exchange views about the percentage of optional subjects. *The scheduling of students' activities* (8) may very well be the area where the greatest break-through in education may occur and where the contribution of the computer may be far more significant than in computer-based instruction of single courses. It may lead to a situation in which each student follows an individual programme according to an individual time table, both being adapted to his specific needs and abilities, instead of all students being collectively processed.

We could further discuss *methods of transferring and testing knowledge, skills, etc. and educational aids* (9,10), but as pointed out earlier, at present the prospects of real break-throughs in this area are rather dim; some of the remaining points might give rise to more valuable discussions, for example: *research policy* (11), *contacts with other universities and with industry* (12 a+b) and *how to cope with the literature* (13).

CLASSIFICATION TABLE

General Characteristics

1. One significant distinction is whether higher education in control engineering aims to train:
   a. control engineers,
   b. control scientists, or:
   c. other engineers and scientists.
2. Another distinction is whether higher education is given as:
   a. ordinary university training, starting from secondary school level and leading to a university degree,
   b. post-graduate training (U.S. style), starting from one university degree and leading to a higher one,
   c. supplementary training (Dresden style), starting from a university degree in another discipline and leading to a university degree (or certificate) of the same level.
   d. post-graduate training (European style), presuming a university degree or equivalent background and aiming at introducing people to control engineering, refreshing control engineers, or training specialists further.
3. A third distinction is whether higher education takes place in:
   a. a conventional department, like that of electrical engineering,
   b. an independent control-engineering department.
4. The studies may further be:
   a. full-time,
   b. sandwiched,
   c. part-time.
5. Studying may be done:
   a. mainly in the university,
   b. mainly outside the university.

Specific Control-Engineering Aspects

6. Formulation of the aims of control-engineering education.
7. Relations to other disciplines:
   a. systems science, computer or computing science or informatics, operations research, economics, etc.,
   b. technology, physics, chemistry, mathematics,
   c. social sciences, ethics, law.
8. Selection and subdivision of the subject-matter, scheduling of students' activities.
9. Methods of transferring knowledge, skills, etc., and educational aids:
   a. formal lectures,
   b. informal lectures,
   c. paper and pencil exercises,
   d. laboratory exercises,
   e. projects,
   f. texts and other aids to individual study.
10. Methods of testing knowledge, examinations.
11. Policy with respect to research and development work.

Organisational Aspects

12. Policies with respect to contacts:
    a. contacts with other universities,
    b. contacts with industry etc.,
    c. attendance of conferences etc.
13. How to cope with the literature
14. Organisation of a control-engineering group.

5. *THE PAPERS*

Let us now briefly review the papers presented in this session.

The paper by *KINDLER* describes some experiences with a part-time (4c), largely extramural (5b), supplementary education (2c) of graduates who received no control-engineering education (1c). Apparently, efforts are being made to adapt both subject matter and time-table to individual needs. A few remarks with respect to points classified in this commentary under the heading *Specific control-engineering aspects* are added.

The paper by *RIABOV* and the present commentary are very much in line with each other. The paper argues that a single type of control engineering education cannot satisfy the needs of a large country, adding that while the most important problem is to determine now what kinds of control engineers will be needed in the future, the discussions are often restricted to topics like subject-matter, ways of teaching, teaching aids and the like. It identifies four classes of engineers, namely:

- class 1 : theoretical research specialists
- class 2 : designers of specific (sub)systems
- class 3 : manufacturing and adjustment specialists
- class 4 : control engineers that keep existing control systems operating and up to date.

I would be inclined to support this classification, although I have the impression that class 2 and class 4 are very much alike and that, in fact, university graduates in either class would be well advised to move back and forth between them from time to time.

The paper then goes on to describe, by way of illustration, the profiles of the training for six different fields of control-engineering, namely (see also the figures given in that paper):

1. applied mathematics (class 1)
2. automatic control systems (class $1\frac{1}{2}$)
3. automation of metallurgical production (class 1)
4. automation and telemechanics (class 2)
5. production of computers (class 3)
6. automation in the process industry

Finally, the author defines those problems that merit further study, all dealing with points 6 to 8 of our classification: what are the aims and what should be the subject-matter?

Two points not discussed in the paper are how the students can make the best choice between these different specialisations, and how much chance they have of getting a job in their own specialty. These two points may, in fact, be serious drawbacks of any early specialisation. It would be interesting if the author could tell us how many of the graduates of these specialisations are now engaged in the type of work they were prepared for.

The paper by *WEISS* gives a candid account of the development of an instrumentation and controls laboratory. It concerns both undergraduate and postgraduate education (2a,b) of different kinds of engineers (1c) in full-time in-school studies (4a,5a), and in particular the laboratory work (9d). A description of the various set-ups is given.

It is interesting to note that the paper reports that the appreciation of laboratory work - and of the small details that so often make or break the success of a system - is being restored in the USA. When reading this paper, many of my European colleagues will, like myself, realise how well off we are with our splendidly equipped laboratories. We can only hope that this paper will encourage and inspire our colleagues in those countries where the financial support by the government is less generous, to make the most of a small budget.

Finally, the outstanding paper by *WESTCOTT* and *BRYANT* concentrates on the policy with respect to research and development work (11), the contacts with industry (12b), and the organisation of a control project (14) of a department of computing and control (3b). It sketches the evolution of a project concerning the control of a five-stand steel cold rolling mill, which was realised in cooperation between Imperial College, British Steel Corporation, General Electric Company and the U.K. Department of Trade and Industry. Readers familiar with cooperation between university and industry or, for that matter, with the wonderland of intramural cooperation between different departments of a single large industry, will enjoy this looking-glass. The paper so bristles with apt comments on the life with an industrial project that it ought to be compulsory reading for everyone participating in one.

University professors have been defined by some unknown wit as people preparing young men for the difficulties of industry they themselves have escaped by becoming professors; therefore, it is heartening to see the serious efforts made at various universities to come face to face with those difficulties. This is the more important because it provides those universities on the one hand with a better idea of what they are educating their students for, and on the other with a more realistic view of what kind of theory is actually needed.

As mentioned by the authors, cooperation between university and industry can take many different forms. Surely the form discussed in their paper is about the most far-reaching. I for one have always preferred to let a cooperation start quite informally and to attend to it carefully as it grows, letting it develop into something more formal only when that turns out to be preferable. It would be interesting to hear from the authors which of the various forms they have encountered they prefer and why.

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To the commentator's knowledge there is no bibliography covering the literature on higher education in control engineering. Therefore, the results of a first attempt to compile such a bibliography is presented in this section. Some selected references to general articles on (higher) education have been added.

The most comprehensive publication is the survey prepared by *FINDEISEN* * for the third IFAC Congress in London, 1966. It merits special mention here, because many newcomers in this field may be unaware of its existence.

The bibliography presented here is bound to be incomplete. Any reader who notices one or more important omissions is invited to inform the commentator, so that a more complete bibliography can be published in due course.

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