Teaching of Science at the College Level[1]

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TEACHING PROBLEMS in one form or another are as old as man himself. The problems vary, however, from time to time with advances in knowledge and ever changing conditions and, because of the variables, will never be solved. Like the rainbow, they recede as we approach solutions. Hence continuous study is necessary. I write as an individual with a background of varied experiences, including that of student, teacher, and administrator, each of which has had greater or lesser influence on my thinking. I have reached certain tentative conclusions but am willing to modify those conclusions in the light of convincing evidence. I am not willing, however, to accept unchallenged every new educational movement that presumes to cure all our ills. The fact that there is so much discussion today of teaching of science at the college level implies criticism of present procedures. On the other hand, the implication may be simply that a good teacher is never satisfied with what he does and is always looking for ways and means of doing a better job. If we are critical, what are the criticisms? Are they just, supported by verifiable evidence, or are they merely rumors and opinions, which gather momentum as they pass from lip to ear? What are the suggested remedies? Will they lead to improvement or merely change?

Before discussing some of the criticisms let us look at the whole problem. Too often the critic looks at only one small segment, such as the lecture method, research, or need for a course in education, forgetting the broad ramifications and implications. There are about eighteen hundred colleges of one kind or another in the United States. These institutions may be somewhat alike or they may be very different, but all of them attempt to educate the youth of the land. Their philosophies, their objectives, and their ways may differ, and they are not too well defined. Equipment in the form of classrooms, laboratories, libraries, teaching staffs, and administrative officers differs widely. Attending these colleges are thousands of students who differ in many ways. Some of them come to college to study and learn; others to attain a certain social status. Still others come with no well-defined purpose. Among those with abilities and with serious purposes, some seek a general education because they think such a background is good for whatever they may do later. Others spend two or three or four years in preprofessional study, usually following curricula outlined somewhat rigidly or specified as entrance requirements by their respective professional schools. I mention these different groups because teaching is more difficult when students of diversified abilities and interests are placed in the same class. Ten years ago, many colleges were approaching the upper limits of their capacities to care for students. Now, with student numbers about doubled, colleges are seriously handicapped for lack of space, proper housing, equipment, and books. Faculties are not only too small—so that classes are too large and teaching loads too great—but the quality has been diluted because there is a scarcity of good, well-trained candidates.

One of the difficulties with all our educational plans is that they cannot be measured with any high degree of accuracy. The end result is the final test and the desired result is not the sum total of accumulated information the student acquires, but men and women of integrity, capable of continued growth, of meeting and solving problems, and of adjusting to changing conditions, successful in their professions and trades, men and women who work for the welfare of their families, their fellowmen, their nation, and the world at large. This end has been reached by devious paths by different men and women, even some with no formal education, and the presumption is that many different kinds of educational programs may still lead students to the same desirable ends. Perhaps the ideals toward which we work, the environment in which we work, and the zeal with which we work are more important than courses, credits, and methods.

Many of us seem to lose our sense of balance, fail to consider facts, and in our discussions of teaching act as though we expected perfection in all teachers—as though college teachers should be required to correct all the ills of students accumulated through 18 years, more or less, of life with parents, secondary school teachers, and other associates of varied shades and hues. Good doctors and good lawyers develop only after years of experience and further study beyond the professional schools. Not all who graduate become good. Only a few become great. The same principle holds for businessmen, bankers, and bakers—and college presidents. Why should we expect more of college teachers? They are human and,

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like others, make mistakes. Their jobs are no less difficult and may even be harder than other jobs. The undertaker may cover up a doctor's mistakes with six feet of earth. The lawyer may befuddle you with words, but the critics look at teacher's mistakes through magnifying glasses and raise their voices for radical reforms without seeing the problem entire, and without knowing what to do and how to do it.

Scientific knowledge has expanded so rapidly and so widely that no one person can know the whole of any of the few larger fields such as physics, chemistry, or zoology. The result of this expansion has been the subdivision of each of these larger fields into lesser fields. In my own day I have seen the American Society of Zoologists give birth to a genetics society, a human genetics society, an evolution society, an ecological society, and others. The entomologists have been isolated so long they have even forgotten they are zoologists. The result is that scientists, including teachers of science, must concentrate their interests and their energies in limited subdivisions. This movement is taking place at the same time that the sciences, in many respects, are moving closer together. Hence the need for teachers to know interrelated fields is greater than ever before, but the difficulty of meeting this need is also greater than ever before. I offer no solution, but recognition of the problem and the difficulties involved is essential. The difficulties that confront teachers of science also confront students of science.

Good teaching cannot be isolated from all the other activities of the college. It is a resultant of many factors, of which the teacher is only one. If the college administration fails to provide a good library, good equipment, good working conditions, time for good teaching, if scholarship is not respected, if extracurricular activities, social affairs, and athletics are overemphasized, if students assume no responsibilities, good teaching becomes the more difficult.

Most of the criticisms we hear today center around beginning teachers. Here again, there is much confusion and, in the absence of facts, erroneous assumptions and conclusions are frequent. First of all, we do not know how much poor teaching takes place and there is no way of getting the information. For effect, exaggerations are the rule. We are apt to lump all poor teaching together and think of young teachers as responsible, when in fact older teachers may also be to blame. Let us not forget, too, that some of our best teachers are young.

Our critics talk much of educating teachers so they can adjust their teaching to the social needs of our time. But who knows what our social needs are? Even if you do, they may be different tomorrow. You may go along with the administration in thinking, or acting as though you thought, that security from the cradle to the grave is our number one social need. With security you may be willing to sit in your easy chair and let politicians tell you what our social needs are and legislate accordingly. On the other hand, I may prefer opportunity to security, hard work instead of an easy chair, and I may wish to play a part in planning and shaping social trends. And how does one teach zoology or any science to meet these needs? Personally, I do not want students, including prospective teachers, to be trained either in college or graduate school to think in grooves. Instead I prefer to educate students to think for themselves, to be capable of meeting and wrestling with their social problems, capable of adjusting and readjusting. Social conditions today are far different from those of fifty years ago or even ten years ago. What will they be ten years from now? Will they be dictated from Moscow? We seem to forget that students live in our social world and that they are continuously bombarded through the media of newspapers, radio, and public addresses, with comments and discussions of social conditions.

If we study criticisms of college teaching over a period of years they seem to come in waves. Not long ago the emphasis was on methods and techniques. We condemned the lecture system and experimented with the project plan, the contract plan, the honors plan, the preceptorial and tutorial plans, and the plan of individualized instruction. We sectioned on the basis of ability, taught classes both large and small, and examined by various methods and devices. As a result of these studies, many of us have concluded that a good teacher may get good results by any method and that he should choose the method he can use to best advantage. Methods then recede somewhat into the background; they are important from a particular teacher's point of view, but none is of universal application. Because of the increased student numbers and the scarcity of teachers, however, we may be compelled to devise new methods and techniques.

The one outstanding criticism of college teaching concerns teacher education. Before we can discuss teacher education intelligently, we need to know where responsibilities lie, particularly since most critics place the responsibilities upon the graduate schools, apparently forgetting that students have lived twenty or thirty years before entering graduate school, and that these earlier years include education in the home, school, college, and in the world at large. Are not these early years the time and these institutions the places to acquire a broad general education, to develop character, habits of study,

scholarly interests, the ability to read with understanding, and to speak and write with clarity? The graduate school is a school for specialization and although it has an important part to play in the education of teachers it should not be expected to make good all the educational deficiences accumulated in former years.

Before discussing particular ways and means of completing the education of college teachers in graduate schools, it may be well to look at present and past methods. You may think that nearly all teachers hold Ph.D. degrees, but such is far from the truth. In 1928 the North Central Association reported that of 8,743 college teachers, only 33.9 percent held Ph.D. degrees. A similar study made in 1945 of 305 member institutions revealed that in 10 percent of the institutions only 10 percent of all teachers held Ph.D. degrees, while in 70 percent of the institutions only 43 percent of all teachers held such degrees. The median for the entire group was less than 35 percent. Such facts must be kept in mind when we discuss the education of teachers, for it is evident that all poor teaching cannot be traced to Ph.D. programs.

What are the graduate schools now doing and what, if any, changes should be made? In answering these questions I am thinking of graduate education at its best, recognizing, however, that some poor graduate teaching is done and that many students now in graduate schools will never be more than mediocre teachers and researchers.

In the past we talked about more rigid selection of students but did little, except in a few universities. Now, with graduate schools crowded beyond their capacities, selection is more generally practiced. Dean Russell pointed out years ago, however, that selections were on the basis of a student's ability to earn good college grades and not on the basis of his abilities to practice a profession. Although there are good students—how many we do not know—who would be misfits in the teaching profession, most of us believe the correlation between high scholastic ability and good teaching is greater than the correlation between low scholastic ability and good teaching. In some places there lurks the thought that scholars should teach only scholars and, as Linn has expressed it, teachers of the lower 80 percent of college students who are not potential scholars should be taught by teachers who are not scholars but merely intelligent and humane.

From whatever angle we look at it, the admissions problem is complicated. Possibly, in time, tests may be devised that will enable us to separate more accurately the sheep from the goats, but until then we shall select as wisely as we can, knowing that misfits cannot be excluded and hoping that college administrators will use greater care and better judgment in selecting their teachers; hoping also that graduate school teachers will more accurately tell the truth in their letters of recommendation.

Even as now selected, graduate students are a heterogeneous lot. A high percentage of them become teachers in high schools, colleges, and universities, and work toward fulfilling requirements for either the M.A. or Ph.D. degree. A smaller number wish to qualify for research positions only. Others come for an additional year or more, for various reasons, and are not candidates for degrees, but prefer to pick and choose at will.

The M.A. degree, as administered in nearly all universities at present, cannot be thought of as preparation for college teaching, even though many so trained are employed as college teachers. The degree may be nothing more than an additional year of college work, or college work plus courses in education. If we dismiss the M.A. degree from consideration the main question is whether the requirements for the Ph.D. degree prepare students for college teaching. It is this degree that has been and still is the focus of attack. Many unkind things have been said about it and about teachers educated by this route.

Just what would the critics have the graduate schools do? If we go back fifteen or twenty years, we find that the Association of American Colleges asked for a course on the American college and another on methods and practice teaching, while the North Central Association asked that graduate schools acquaint prospective teachers with the literature on student personnel, college curricula, college instruction, and college organization and administration. Judd recommended that we train all prospective college teachers "in the methods and results of inquiry in the subjects which they are to teach, in the methods of critical evaluation of the results of teaching." He also wanted us to understand the American educational system. In addition to the recommendations of the North Central Association, Haggerty added that all teachers should be trained in the techniques of educational research. Suzzallo specified a minimum of three courses, one on the American school system, a second on the psychology of learning, and a third on practice teaching. Suzzallo also recommended that we send prospective teachers to schools of education, leaving scholars in the graduate schools. In response to the request of the Association of American Colleges, the Association of American Universities sanctioned a course on the problems of the college and another on methods and teaching under supervision, both to be given by subject-matter departments, and both to be optional.

College teachers themselves, through the American Association of University Professors, recommended:

(a) That the academic departments consider what they might do to give their graduate students necessary training and supervision in the teaching of their respective subjects.

(b) That they sanction an optional seminar on problems of American education with special reference to the college, to be given by the school of education or by this school in cooperation with the academic departments.

From the report of the President's Commission on Higher Education I quote:

1. The most conspicuous weakness of the current graduate programs is the failure to provide potential faculty members with the basic skills and the art necessary to impart knowledge to others.

2. The failure of individuals to learn how to teach is largely the failure of the present graduate school system. Inflexible requirements for the degree, the formality and dispersion of the established curriculum, the absence of programs designed to develop skill in presenting subject matter and the lack of appropriate guidance have been largely responsible for the fact that advanced degrees frequently do not indicate an ability to teach.

3. This Commission holds that the academic offerings of the graduate schools should be suited to the needs of students who are preparing for careers in higher education.

4. He [the student] should be given the opportunity to become especially proficient in some area of human knowledge, but not to the extent of overspecialization. The degree of specialization should vary somewhat with the teaching field, but in general it should follow the professional rather than the academic pattern. [Note the word *professional!*]

5. Drastic changes of policy may be necessary in many graduate schools if they are to plan teacher preparation studies which will be professionally realistic.

6. The successful completion of the teacher preparation program should be indicated by some suitable designation. [Here is an entering wedge to teacher certification.]

7. This Commission recommends that the graduate schools take advantage of the opportunity and the obligation to make a distinguished contribution through providing internship training for those who plan to enter these different fields.

8. The faculty member who is to grow professionally and preserve his vitality of outlook must be equipped to grow independently. [We differ here only as to methods of equipping teachers so they may grow independently.]

9. This Commission proposes the extension of formalized programs aimed at teaching the methods of investigation. (Note the expression *formalized programs.* Several years ago I read a book of more than 600 pages on how to do research in education. The one thing I learned from that profound discussion was that if I wanted to do research I must first select a problem.]

For the past fifteen years the chairman of the President's Commission has been expounding reforms similar to those expressed in the Commission's report. Recently a conference on the preparation of college teachers was held in Chicago. It was sponsored by the American Council on Education and the U. S. Office of Education. I quote only from the remarks made by Commissioner McGrath:

1. Graduate faculties are attempting to perform two dissimilar functions without apparently recognizing their difference. [I didn't know we were so dumb.]

2. The primary responsibility of the graduate school is to produce creative minds. It should educate scholars and research workers, not college teachers. The training of teachers should be the responsibility of a professional division of the university. [In other words, the school of education.]

What do teachers of science think about the education of college teachers? I speak for myself only. I do think it important, however, that other science teachers speak before it is too late. Who knows more about how teachers should be educated than teachers themselves, even though Capen has called us laymen with respect to educational questions? If my information is correct, there is not more than one person on the President's Commission who is now active in the teaching profession. Some have been teachers but when a teacher becomes an administrator he seems to undergo a complete metamorphosis.

Can teachers of science defend the Ph.D. program as the best way to educate college teachers of science? The answer to these questions will depend somewhat upon what we think good teaching is. Committee U of the American Association of University Professors has defined good teaching as that which stimulates the student to learn as a result of his own efforts. A similar concept of teaching was expressed by Meiklejohn when he said that teaching is not the giving of information, but the stimulating and directing of the mind by other minds that are going in the same direction. President Lowell has said that good teaching should be self-education under guidance. With these concepts I agree and what follows will be colored by them.

Requirements for the Ph.D. degree, as judged by catalogue descriptions, are much alike the country over and consist of four major items.

1. Broader and deeper knowledge of a field of specialization.

2. More limited knowledge of fields or a field related to the major field of specialization.

3. The thesis.

4. The final comprehensive examination.

All these requirements are variables, depending upon the teachers and administrators who supervise and enforce them and upon the students who are also

variables. The program is not rigid and inflexible, as some would have you believe, but is built around the needs of the student by a committee working with the student. Within the broad general framework of the requirements as stated, the commitee has much latitude and may even cut across departmental lines. A broad knowledge of the field of specialization may be stressed more by some than by others. The same statement may be applied to related fields. Perhaps the thesis is the most variable of all. You must be familiar with the diatribes written on the subject. In some instances, so it is said, it may begin with the trivial and end with the obvious, while in others an essay may be substituted. At best it may be an exciting journey of exploration into the unknown. The final comprehensive examination may be superficial or exacting.

In defending these requirements I do so on the assumption that they are enforced with fairness, justice, and flexibility, but at the same time with high scholastic standards, keeping in mind the development of the individual student to the point where he has the foundation for continued growth and where he can do either teaching or research or both with some degree of efficiency. No one, to the best of my knowledge, has proclaimed that students who complete requirements for the Ph.D. degree are more than beginners at either teaching or research.

I also assume that college graduates applying for entrance will be carefully screened with respect to scholastic abilities and previous education, and insofar as possible with respect to their interests and abilities in teaching. No one can take any and all comers and make good teachers of them.

Perhaps most or all of us would agree that a broad knowledge of the field of specialization and related fields is desirable, even though we would not say it is necessary. One difficulty, however, lies in the fact that knowledge has expanded to the point where only a few people are able to carry out the full intent of these requirements.

In discussing the thesis requirement, I assume that the student, after consultation with teachers, selects a problem, an unknown, which he wishes to study and explore. The problem should not be a small, circumscribed one which, when the investigation is completed, leaves nothing more to do. Preferably, the problem should be an approach to, or a segment of, a larger field of investigation. When this type of thesis is completed the unknowns have increased because the student's range of vision has been enlarged and he is led on and on so that he becomes an investigator for the rest of his life.

I assume also that the student does the work with a minimum of guidance by the teacher. There may be some floundering, some loss in following blind alleys, some backtracking, but the student must learn to work and to think independently, and he does not acquire these qualities if he is continuously under the direction and supervision of a teacher who tells him what to look for around the corner and the next corner.

The thesis is required for the purpose of teaching students to do research, but it also has another important function. I challenge you to find a better way of testing and developing the student's interests, powers of observation, his initiative, imagination, drive, judgment, and abilities to interpret data and solve problems.

No one, to my knowledge, has criticized the final comprehensive examination, and so it seems to need no defense.

What about courses in education? Should they be required, and if so should they replace some of the present Ph.D. requirements, or should they be added to them? I have already stated the insistent demands of the critics. To me, this is one of the most important questions facing colleges, graduate schools, and teachers. Our ideas of what good teaching is, as well as our philosophy of education, are at stake.

The trend in many colleges has been toward professionalized and vocational courses and curricula, in which students are taught specific things in specific ways in order to prepare for specific jobs. Perhaps teachers of these students should also be taught in specific ways. But I am not discussing the education of this kind of teacher. Instead, I am thinking of teachers in colleges that still offer opportunities for students to learn to live as well as earn a living, where scholarship is respected, where it is held that the acquisition of knowledge is an end in itself worth attaining, where students may acquire a general education. Such teachers must be able to think for themselves, to see, to meet, and to solve problems as they arise. They must not be cast in bronze over a hypothetical model of clay.

I have no objections to college students' taking a course in the philosophy or history of education, or a course in psychology; but how much use a college teacher makes of such courses in the classroom no one knows, and there can be no reason for introducing them into the graduate program unless they are of direct practical value. I see no need either in college or graduate school for a course on the American college or the American school system. Neither do I see a need in the graduate school for a course on the techniques of educational research. They are not so intricate that they cannot be mastered whenever a need for their use arises. Here is another example of minds running in the well-worn

groove—the assumption that everything we learn must be taught in courses.

While I would refuse requests for courses in education, I suggest that graduate schools consider the need for practice teaching and a seminar on college problems. To the educationists I suggest that they write some good books and include material they think college teachers should know and use but omit nonessential details. We think we are capable of reading and understanding, and we also think we are capable of judging values.

What I have said will not satisfy the critics. Their requests, however, are not supported by convincing evidence that better teaching would result if their advice were followed, or even that they themselves are better teachers.

After forty years of experience, I presume I should be wise enough to tell how science should be taught in college and how a science teacher should be educated, but the longer I live the less sure I am of the answers to such questions and the surer I am that no one else has final answers. This does not imply, however, that one answer is as good as another.

If I were to venture to make a few suggestions, not because they are new but by way of emphasis, they would run something like this. To young people thinking of entering the profession, I would say: Be sure you want to make teaching your life work and that you have the personal qualifications for success. If you are looking for an easy job, or can't be satisfied with a modest income, look elsewhere. If you decide to teach, educate yourself as best you can but there is no one pattern that must be followed. I suggest you emphasize both breadth and depth. Don't neglect the humanities, social sciences, and fine arts, for they too will add breadth worthy of acquisition, and add to your enjoyment of life. See and learn as much of the world and of peoples as possible. Learn to do research, for research activity will do much to keep you a live, virile teacher. Continue to be a student of the subject you teach and of teaching problems. You will never reach perfection, for it is neither in your genes nor in the environment. Know how good teachers teach, listen to suggestions and criticisms, then make your own decisions in the light of what you are attempting to do. Be yourself. Don't let your enthusiasm for your subject cause you to attempt to develop all students into specialists. Most students have other interests, and want science merely to add to their breadth of education or to satisfy their curiosity. Such students are worthy of your best efforts as a teacher. Never lose sight of the fact that a good teacher guides, and that a student learns by his own efforts. Encourage the reading of good books. Teach some things by example. By all means, remember your students will be citizens of the United States of America and that they will play significant parts in the development of our country. Differentiate sharply between propaganda, indoctrination, and education.

The Role of the Time Factor in Protein Synthesis[1]

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IT IS A FUNDAMENTAL CONCEPT that proteins are composed of amino acids and that the number and spatial arrangement of these building stones characterize the individual protein. This leads logically to the hypothesis that protein synthesis can proceed only if all the building stones involved are available.

This truism more or less exhausts our knowledge of the mechanism of protein synthesis. Cannon (*4*) recently emphasized the fact that in spite of our growing knowledge of the catabolic phase of protein metabolism, there are wide gaps in our understanding of its anabolic phase, and Northrop (*20*) called attention to our lack of knowledge concerning not only the energetics of protein synthesis but also the nature of the basic building stones of proteins: viz., whether proteins are synthesized directly from amino acids or from larger intermediary building stones, so-called plasteins.

The plastein theory of protein synthesis in its original naive form (Sawjalow, 1899), or in its recent revision, is based on the reversibility of protein hydrolysis *in vitro* and therefore can hardly account for the specificity of the synthesized proteins.

Even the epochal experiments of Schoenheimer and his colleagues shed little light on the problems of protein anabolism. The ease with which labeled amino acids have been incorporated into protein, however, forecasts a drastic revision of our current ideas on the rigid structure of living protein.

[1] Based on a lecture given at the Gordon Research Conferences, AAAS, August 14, 1949.