CREATIVITY AND RESEARCH IN THE UNIVERSITY

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1. WHAT IS CREATIVITY?

Recently, I reviewed an excellent collection of carefully written articles on Creativity. Examining this series of essays by experts in such fields as psychology, psychiatry, human engineering, education, and allied areas, I was struck by the fact that almost unanimously they agreed that there existed no precise or intrinsic description of what is meant by the term "creative".

Add to this the fact that creativity is often unrecognized, and almost invariably unappreciated, and we see that the task of education for creativity is complicated to a remarkable degree. There is, however, no reason for discouragement since in the majority of cases where we are training human beings to solve human problems we face this vagueness, ambiguity, and lack of dichotomy.

Despite this absence of clear-cut problems, and clear-cut objectives, much can be done. Let us begin by using a classical mathematical device to introduce a meaningful discussion.

2. PROJECTION AND PRODUCTIVITY.

The trick we use is that of projection. If a quantity or quality cannot be studied directly, let us study it by means of its interactions, or projections. Consequently, in our attempt to study "creativity", we shall examine one of the acknowledged results of creativity—research.

Let us then narrow our focus and discuss a variety of factors which foster significant research, and what aspects of contemporary college and university environment militate against it.

3. EVALUATION OF RESEARCH.

Our original objective, an examination and evaluation of creativity, thus leads us willy-nilly into the delicate and difficult task of evaluating research. As far as most academicians are concerned, this is neither a popular, tactful, nor orthodox activity. The word "research" is most commonly used as a conclusion of a catechism in the following fashion.

"What are you doing?" "Research." End of conversation.

Graduate students are in the main trained to avoid any discussion of the worth of research, or the motivation for research. Questions in this vein are no more allowable within their conceptual framework than a question to a medieval monk concerning his reasons for studying theology. There are good and bad aspects to this concept of research as an act of faith, but faith is not enough in an area of major importance to culture and society.

In the university, there is apparently an agreement not to assign priorities. Priorities, after all, involve that taboo term, value judgment. A justified concern over academic and intellectual freedom has led, in many instances, to a refusal to accept any standards at all. We see this phenomenon in contemporary art, music, and literature.

In actuality, when different departments of a university receive different levels of financial support, for salary, for students, for trips to meetings, symposia, and secretarial help, then for all practical and operational purposes, value judgments have been made. A decision and an action imply a value judgment.

Since there are implicit and de facto evaluations of research in the colleges and universities, and certainly in the military and business organizations that support so much of contemporary research, it is worthwhile to examine these matters in detail. As we shall see, in this way, we come across a number of factors which strongly influence the education of students.

4. LEVELS OF CREATIVITY.

It must be immediately emphasized that it is extraordinarily difficult to assign utilities and priorities to research, and to different types of intellectual activity in general. It may help, however, in the course of an investigation of this nature, to recognize that there are many different types of creativity, and even different levels of creativity. Certainly, there is a great distinction to be made between creative activity within a philosophical or scientific system, and that involved in constructing a new philosophical or scientific system.

For example, the discovery of Neptune, using the concepts of Newtonian mechanics and a certain amount of mathematical ingenuity, was a great achievement, considered by many as the major achievement of classical astronomy. Nevertheless, it is of a lower level on the creative scale than, let us say, Einstein's relativity theory.

These points are important because it seems quite plausible that different types of education are called for to prepare students for different types of research activity. At the present time, our educational system is well-geared to produce an Adams or Leverrier, but not an Einstein. The latter's own remarks in his autobiography bear out this observation.

5. SCIENTIFIC PHILOSOPHY.

Any evaluation of research, (to determine, for example, whether it represents creative effort or not, and if so, what level), forces us to introduce ideas and concepts which are seldom mentioned in the hearing of the young—the young graduate student that is. Frequently, by the time the young researcher has the intellectual basis to consider them, it is too late for him to apply them, or even appreciate them.

The study of human aims, objectives, values, utilities, purposes, esthetics, and so on, is the study of philosophy. Most of us have had such boring and meaningless courses in philosophy in college that we are quite sensibly prejudiced against the very word. This is unfortunate. It is the most important of all courses and study areas since our day-to-day happiness, and long-term existence, depend crucially upon our personal philosophy of life.

In particular, anyone committed to scientific research as a dominant theme in his life requires the help of scientific philosophy in guiding his activities. Probably the greatest weakness of the modern educational system is the absence of training in the area of philosophy by people qualified to talk about these matters. This is due to the fact that it is very rare that anyone but a working scientist can present the basic ideas in a lucid and sensible way, and he is usually too busy doing research to talk about it.

If we start thinking in this direction, we realize very quickly that it is necessary to consider not only theories, but theories about theories. Facts are multiplying at an exponential rate, and we all know how easy it is for student and faculty alike to become engulfed in a sea of facts. But the same is not true about theories. One of the triumphs of science is the systematic reduction of theories to fewer and more fundamental theories, the ruthless application of Ockham's razor.

6. CREATIVITY AND THE PHYSICAL WORLD.

What is it that leads to the creation of new theories? Is it the systematic examination of old theories with a view to generalization, axiomization, and organization? Important as it is, this procedure is not sufficient. It is extremely useful and meaningful as far as pedagogy is concerned, (when carefully done, as opposed to the way it is usually done), and for applications, and generally speaking for creative work within the system. If, however, we are really concerned with higher level creativity, then we must emphasize the significance of the influence of the real world. Theory has had an enormous effect upon the world we live in, (both good and bad). The history of mathematics and science shows that the real world has had an even greater influence upon theory. Indeed, it is difficult to see how it could be otherwise.

It has been repeatedly emphasized, even in our time, by the very greatest of mathematicians, men like Weyl and von Neumann, that even the most abstract of all human intellectual activities, mathematics, withers and atrophies without the constant infusion of new ideas from the physical world around us.

Despite the obvious truth of these remarks, buttressed by the history of mathematics over the last two hundred years, we see in many parts of the university a violent and shuddering withdrawal from both the human and physical world. In mathematics, for example, there is now a continuing and wearing struggle between two factions, those who want close contact with the physicist, engineer, biologist, economist, physician, and so on, and those who feel that any contact between mathematics and the real world is profanation of the sacred mysteries. The first group feels that it is absolutely essential for mathematics to be illustrated and motivated by physical processes; the second group, headed by the Bourbaki and their American devotees, insist that mathematics must remain "pure", abstract, unmotivated and unresponsive to the society in which it exists.

7. THEORY AND PRACTICE.

In this connection, it is interesting to observe the difference between what might be imagined to be the case and what has actually occurred. Without knowing the facts, it is tempting to conjecture that the armchair mathematician has all the best of it. He has, after all, the privilege of constructing arbitrary sets of axioms, of playing with them, developing them, and modifying them, and even of throwing them away if they are esthetically displeasing, or lead to problems which are too difficult. Presumably, infinitely many artificial universes of meaningful mathematical content can be constructed in this fashion.

Yet, oddly enough, referring to the history of mathematics, this is not the case. The most interesting and significant areas of mathematics, either in the origin or in their development, or both, are directly connected with the phenomena and properties of the physical world. The lineage of the "purest of the pure" theories can be traced back to immigrants from astronomy and physics at most 50 or 100 years ago. The reader may immediately counter with the two words "number theory". Yet I think that a few minutes thought will lead to the acceptance of the idea that this is also a theory generated by the simplest of physical experiments, to wit, the observation of the properties of integers. If there is any real input to mathematics, it is, as many mathematicians have observed, the positive integers, the counting tool.

From another point of view, if we attempt to define great mathematics, we encounter severe difficulties. Yet, if we use the projection technique once again, we can proceed by means of the definition: great mathematics is what great mathematicians do. Fortunately, there is general agreement as to who have been the great mathematicians over the last three hundred years.

If we list some of the names, Fermat, Newton, Leibniz, Euler, Cauchy, Gauss, Jacobi, Riemann, Poincaré, Hilbert, Weyl, von Neumann, we are immediately struck by the fact that all of these people obtained great stimulation from the physical world. So much so, that many of them would be contemptuously dismissed by the Bourbaki as "applied mathematicians". Interestingly enough, in substantiation of my feeling that number theory has physical origins, all of these named were extremely interested in number theory and many of them made major contributions.

It is reasonable to presume that a mind that is fascinated by the puzzle of explaining the regularity of the properties of light or magnetism will be equally intrigued by the problem of understanding the regularities of prime numbers.

Returning to the mainstream of the argument, this list of names would seem to illustrate the point that the way to train an individual to be creative in the theoretical domain is to keep the image of the real world constantly in front of him, and simultaneously to teach him how to abstract ideas and problems from the phenomena that he observes.

A fruitful technique for generating new abstract theories is to examine the world around us, or inside us, to fasten upon significant problems, and then to try and analyze these problems. If we are concerned with creativity within the system, we can afford to be theory-oriented; if we are concerned with creativity outside of the system, we must be problem-oriented.

The usual feedback process will then take over. Theories developed in one area will have applications in another area, and back into classical mathematics. Re-examination of old problems and application of new techniques will generate new problems, and so on.

In some cases, and let us cite group theory, algebraic number theory, and topology, theories seem at the moment capable of sustaining themselves by means of internal interaction without any further stimulus from the outside world. It is not clear, in view of the extraordinary increase in the number of research mathematicians over the last 25 years, that this is a continuing state of affairs. Examining what has happened in a number of areas over the last decade, there is a strong possibility that there will be a greater and greater increase in formalism with a corresponding decrease in density of significance. These are possibilities that should be taken into account when training graduate students and directing them into research areas. What is now quite fashionable may not be a live field ten years from now.

8. RESEARCH IN INNER SPACE.

The reader may, however, feel that all or, at least, much of what has been said above, is very well, but where do we find the inspiration for new theories. To illustrate how easy it is to pick problems from the world we inhabit, consider some of the phenomena associated with the human brain. In the familiar processes of memory, thinking, consciousness, we face intellectual challenges far surpassing in difficulty, (and even in comprehension of where the difficulties lie) any of problems of classical and modern physics. Amazing as it may seem, the fact is that we haven't the faintest understanding of what human memory is and how it operates. We don't even know how many memories there are!

It is rather amusing to point out that many people feel at the present time that the appropriate route to the development of really efficient computers for the solution of scientific problems in physics, engineering, biology, and what have you, may well be through the field of neurophysiology.

The basic defect of current computers lies in their "feeblemindedness" as far as their "memory" (rapid access storage) is concerned. At the present time, the most readily accessible commercial computer has a capacity of 32,000 ten digit numbers. This can be "soupedup" by various devices, at some slight cost in time and accuracy, to 64,000 or even 96,000, and some new commercial computers are in the 100,000 range. Individual computers, requiring specialized and difficult programs, have rapid access storages perhaps twice as large. Furthermore, granted the existence of computer-technology administrators with some understanding of the real needs of current science, we could have a fast memory of about 10^6 readily available.

Compare, however, these capacities which seem large, with the ability of even an untrained mind to store and retrieve information rapidly. How does the human mind remember names, dates, places, descriptions of times and events years in the past? How do we recreate an entire scene in an instant? Nobody knows.

Many outstanding problems in physics, questions in hydrodynamics involving three-dimensional equations, questions in many-body physics, questions in control theory, could be tackled systematically with even an order of magnitude improvement in capacity and speed. With a rapid access storage of 10^9 and a multiplication time or retrieval time 1/100th of that at the present, we could provide the backlog of worked out examples and experience which provides the "intuition" necessary for the understanding and construction of a sophisticated theory.

9. ORIENTATION FOR CREATIVITY.

I maintain that we can produce new results and new ideas by directing graduate students of ordinary ability and intelligence into new areas containing good problems.

I do not believe that creative ideas will arise with anywhere near the same frequency from students of any degree of brilliance funneled into worked out, sterile fields.

There are exceptions, of course. Geniuses will do well under virtually any circumstance. But we are not talking about geniuses when we talk about the educational system. We know less about genius than we know about creativity.

We do want to increase the probability of having brilliant students produce significant results. This requires butting heads with the adherents to scientific fashion, and with those who want to be culturally secure by following the acknowledged leaders. We cannot expect to produce new ideas and a new intellectual climate if we train students in the mathematical, philosophical and cultural web of Gottingen of 1910, of Princeton of 1932, or of Paris of 1946.

It is essential to introduce a more sophisticated, adaptive element into our university system. Students and faculty must be educated in a way which permits them to understand that whatever is, is an approximation to what could be; that not only theories and techniques in a field wax and wane over time, but that even fields themselves lose significance.

This does not mean that we discard the elegant edifices constructed by our masters. We honor this research best by preserving its spirit and pressing forward to new and more challenging areas.

Flexibility is, of course, always easier to demand of someone else. We all know how difficult it is to present a course the very first time. It involves thought and effort, almost "blood, sweat, and tears". But it is the only way of meeting one's obligations to students if one is a teacher.

10. FASHION AND SNOBBERY.

It is, perhaps, not generally recognized how much fashion and snobbery affect the scientific and intellectual worlds. It is, of course, inevitable since scientists are human beings and wherever there are human beings there is bound to be emotion and prejudice. But if we are alert for these effects and if we take steps to control them, we can mitigate their influence.

Let me discuss two examples, one of snobbery and one of fashion, which illustrate how irrational behavior on the part of people trained to be rational effectively diverts research talent from fields that need it desperately.

Let us begin with snobbery. At the present time, the major problems that dominate our civilization, and threaten it, are not within the physical or mathematical areas. The basic problems that confront us are those involving the interactions of human beings with other human beings and with themselves, political problems, social problems, economic problems, problems of emotion and prejudice.

Clearly, these problems of the social sciences are far more significant than any of those of the physical sciences. Not so clearly to those who have not studied these fields is it known that these problems are far more difficult to treat in a rational fashion.

In particular, it is extremely difficult, and in some cases impossible, to treat these problems by means of equations, or even by means of numbers. Since it is nowadays fashionable to treat all problems by means of numbers, this fallacy has two consequences. We have, first of all, a great deal of pseudo-science in the social sciences, masquerading behind a facade of mathematics, and secondly we have a rejection of these fields in favor of the easier, neater, currently more glamorous, fields of mathematics and physics.

At the present time, a disproportionate fraction of our most talented students are going into the physical sciences and mathematics. In the first place, this is bad for society; in the second place, it is bad for the students. There just isn't enough room inside the nucleus of the atom for all those who want to work there.

Let me now illustrate fashion. When John von Neumann became interested in digital computers, as an aid to the treatment and understanding of problems in fluid dynamics and meteorology, and other scientific problems, a number of his mathematical peers at the Institute for Advanced Study thought it rather amusing to stop him occasionally in the halls and ask, "Well, Johnny, still working with arithemetic?"

Now, clearly, there was no digital computer at Gottingen in 1910. Although Gauss, one hundred years before, appreciated very clearly what a digital computer meant, having himself spent three agonizing months on the calculation of the orbit of a minor planet, Ceres, this was not understood at Gottingen in 1910. Nor, surprisingly, is it understood in the Mathematics Departments at Princeton, Harvard, or University of Chicago in 1964.

The training of graduate students at these, and many other lesser universities goes on as if this amazing device did not exist. It is very sad to follow the careers of a number of the Ph.D.'s from these and many other universities. They obtain their degrees in some esoteric part of a branch of an abstract field. They obtain a post-graduate fellowship, and continue in the area of their doctorate. A very few break through into new domains. The great majority, deprived of the inspiration and vision of their thesis advisor, find that they have no capacity for independent research in their field.

They have no ability to generate new problems. In desperation, many leave mathematics completely, or accept fate and console themselves with the teaching of routine courses in the university.

If these very same people are directed into any of the new fields, problems are forced upon them. Frequently, we see students of moderate ability and intelligence doing very well in new fields, while extremely brilliant students in older, worked out fields fail dismally.

There are scientific values and there are human values. When problems are assigned to students, we must think not only in terms of the intrinsic worth of the solution of the problem, but also of the worth of the student as a human being and of his future role in society. Education for creativity is important as far as the student and society are concerned, as well as being important to the development of the field.

11. THE UNIVERSITY AND THE WORLD.

There are many who would tackle the problem of providing better opportunities for research by creating more research institutes, divorced from the universities. I am thoroughly opposed to such research institutes, of which the Institute for Advanced Study is a prime example. The university is the primary seat of research at the present time and should remain so if we wish to turn out the types of students we desire.

When creative people are deprived of students, as much a sin is being committed as when they are deprived of opportunity to do their work. Students, especially the irreverent ones who ask "Why did you do that? Why not this?" are extremely valuable to the professor expounding his theories.

Secondly, I feel that it is extremely dangerous for any group of people to consider themselves outside of society, in some Shangrila where they have no influence upon the world and therefore no responsibility to it.

The university is not a monastery or a convent for those who wish to retire from the turmoil of living. This has significance as far as the teaching of even the most abstract subjects is concerned, which is why I keep using mathematics as an illustration. As pointed out above, even in this field the greater part of most significant and most beautiful mathematics has been directly inspired by the physical world. The best teaching in mathematics is that which continally intertwines the abstract with the real.

12. THE RESPONSIBILITY OF TEACHERS.

A faculty member in a graduate school should face the fact that he is responsible to a great extent for the life and happiness of his graduate students. Supposedly, a student who starts graduate life at 21 years of age, after three years of working toward a Ph.D., should have his whole life ahead of him and be able to turn in many directions. In actuality, if he has been trained in a narrow specialty and is faced with the necessity of getting a job, he will take a job doing what he can do. It takes an unusual 30 year old to accept the fact that six or seven years ago he wrote a meaningless thesis in a trivial field and must now learn something new and meaningful. It is difficult enough if it is merely a matter of academic retraining; it is practically impossible if it is a matter of philosophical retraining.

There is a moral issue here which is not accepted in general. This moral issue, this question of responsibility to the student and to a society which must cope with the poorly trained and possibly discontented student, ties in with our previous ideas on the evaluation of research. I do not profess that I know the precise way to consider these matters, nor that a precise way exists, but certainly the issue must be brought out into the open and various analyses made.

13. GRADUATE SCHOOLS AND PRODUCTIVITY.

Can we find a better way of operating graduate schools? I do not know what the figures are on graduate students who drop out of graduate school before obtaining the union card, the Ph.D. But, from personal experience over 20 years or so, the figures must be considerable. It is easy to dismiss the subject with the comment that these people are not good enough to make it, and therefore it is all for the best. Unfortunately, we know that this is not the case. In all levels of school, the "dropouts" contain a large number of superior students as well as those below par.

I submit the thesis that people of any level of normal intelligence can be stimulated intellectually. The way to do this is to match the presentation and the problems to the abilities. This is part of the responsibility problem mentioned above.

Not every graduate student can do independent research on a respectable level. But they can be directed into fields and problem areas where their talents can be used. A student in the proper area, properly oriented, will have research problems thrust upon him. Even if he cannot use his thesis as a launching pad for further research, his own experience will make him a better teacher, consultant, and so on. The psychological value to the individual of having achieved something is very great.

14. CREATIVITY, ORIGINALITY AND INGENUITY.

I have always been opposed to puzzles and to mathematical puzzles in particular, because I feel that they foster incorrect impressions about mathematics. Mathematics is not a collection of puzzles to be resolved by various ad hoc ingenious techniques.

My fundamental point is that real creativity and originality have little to do with ingenuity, and, on the whole, ingenuity is something which should not be used.

If one has to use ingenuity in the solution of problems, it means that they are not thoroughly understood.

Particular results should follow as applications of a body of organized knowledge and organized techniques. Time and time again, mathematical results have been obtained by means of long, arduous and ingenious arguments. Then, properly understood and analyzed, they are derived very easily by means of different routes.

A good mathematician tries to avoid ingenuity. He wants to turn the crank of a general theory and have the results fall out naturally. Perhaps a prime example of this is Poincaré. When reading his works, one is always struck by the logical simplicity and lucid organization of his ideas.

This is pertinent to the question of training for creativity. It is not sufficient to present results and facts. If we want students to be creative, we must examine the structures of theories and try to understand what constitutes an advance and what does not, and where the basic ideas came from.

15. PROTECTION OF THE INTELLECTUALS.

Let me make one last point as far as the education for creativity in the colleges is concerned. At the present time, our school system, starting from the elementary grades is filled with a number of individuals who fear and dislike brilliant students. There are many reasons for this, ranging from their own experiences in school to the fact that brilliant students are less inclined to follow rules unquestioningly and more likely to ask embarrassing questions in class.

In the colleges and universities, we frequently find that the deans and chairmen of the departments are not those who have made their reputations in research. Quite naturally, those with talent in research don't want to involve themselves in the time-consuming matters of administration. If, however, it is realized that this administration covers the selection of faculty, the choice and support of graduate students, the acquisition of research contracts, then it seems clear that those sincerely concerned with education for creativity must assume some administrative chores. To educate for creativity, we must educate for responsibility as well.

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*Let us cite the following paper which discusses some of the points raised above in greater detail and presents a number of interesting references, C. Hyman, "Therefore, Let us be Tolerant of Each Other's Research," American Scientist, December 1963, pp. 367A-378A.