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TEACHING HIGH SCHOOL BIOLOGY--A GUIDE TO WORKING WITH POTENTIAL BIOLOGISTS.

BY- BRANDWEIN, PAUL F. AND OTHERS
AMERICAN INST. OF BIOLOGICAL SCIENCES

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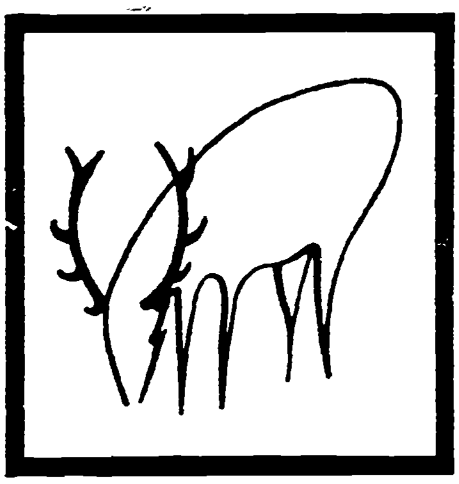
THIS VOLUME CONTAINS A COLLECTION OF PAPERS CONCERNING GIFTED HIGH SCHOOL STUDENTS AND IDENTIFIES PROCEDURES TEACHERS CAN USE TO GUIDE SUCH STUDENTS IN BIOLOGICAL INVESTIGATIONS. THE FIRST FOUR CHAPTERS SUMMARIZE CURRENT INFORMATION ABOUT (1) TRAITS OF CREATIVE STUDENTS, (2) PROMISING PROCEDURES AND TECHNIQUES FOR WORKING WITH CAPABLE BIOLOGY STUDENTS, (3) THE NECESSARY SCHOOL ENVIRONMENT AND ASSISTANCE TO GIVE STUDENTS WHO ARE STARTING INVESTIGATIONS, AND (4) NEEDS OF LIBRARIES ADEQUATE FOR STUDENT RESEARCH. CHAPTER FIVE IS A BIBLIOGRAPHY CONCERNING GIFTED STUDENTS. THE APPENDIXES INCLUDE SPECIFIC INFORMATION ABOUT (1) A PROJECT ROOM EQUIPPED FOR BIOLOGY, (2) SAFETY PRACTICES, (3) ANIMAL CARE, (4) KINDS OF STUDENT PROJECTS, (5) TYPES OF STUDENT REPORTS, (6) EXAMPLES OF TEACHER PROJECTS, (7) A SAMPLE BIOLOGY SEMINAR, (8) A COMMUNITY SEMINAR PROJECT, AND (9) A NATIONAL PROJECT TO STIMULATE INDIVIDUAL WORK IN BIOLOGY. (RS)



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American Institute of Biological Sciences
2000 P Street, N.W.
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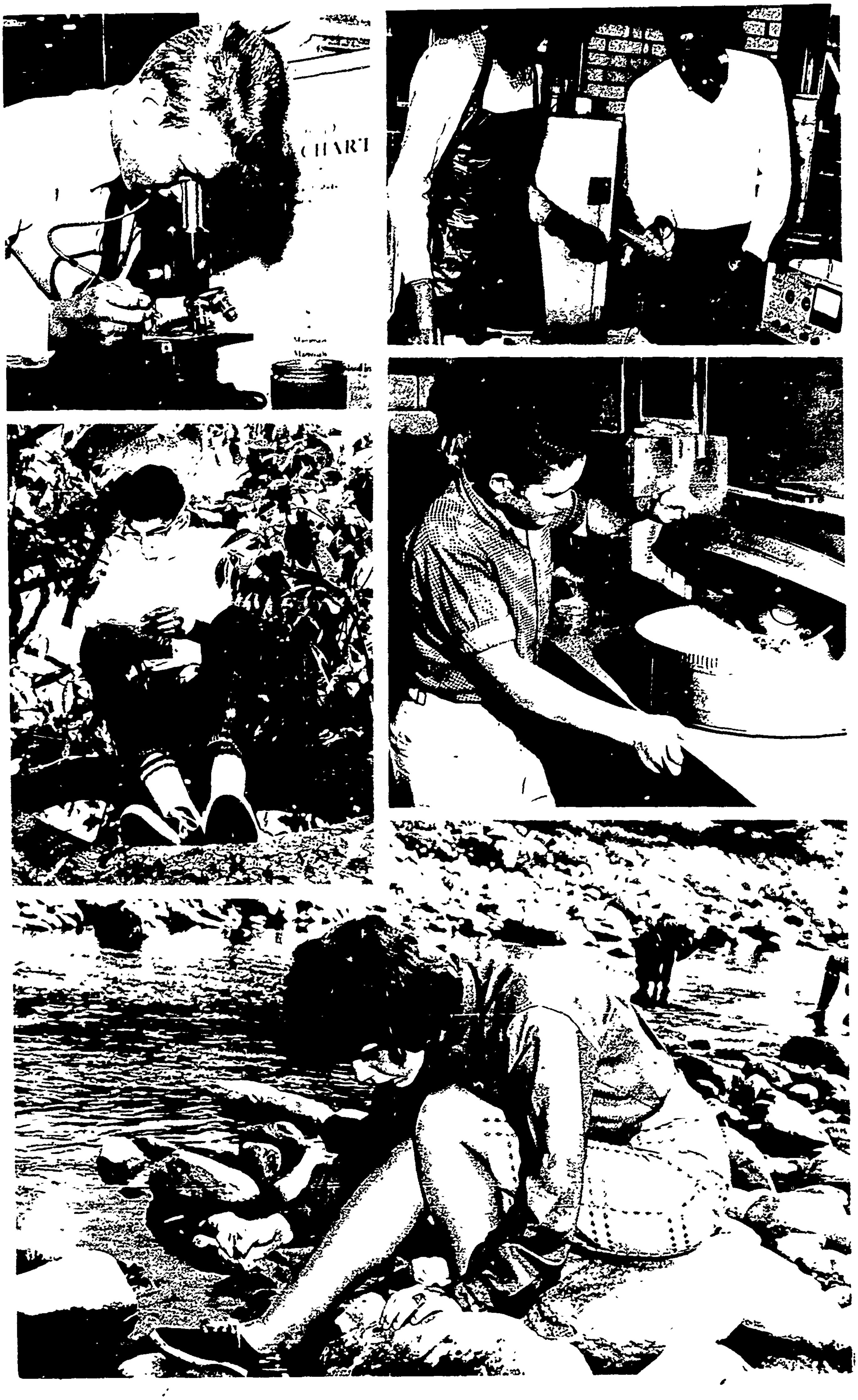
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FOREWORD

The Biological Sciences Curriculum Study, with major financial support from the National Science Foundation, is one of the principal educational programs of the American Institute of Biological Sciences. The Curriculum Study, shortly after its organization in January, 1959, established headquarters on the campus of the University of Colorado. The BSCS Steering Committee, under the chairmanship of Dr. Bentley Glass of The Johns Hopkins University, focussed the immediate attention of the Study on the secondary school curriculum in biology.

The BSCS Committee on Gifted Students, under the chairmanship of Dr. Paul Brandwein, prepared a series of investigations for high school students of high ability and motivation. These investigations have been well received by teachers and students in the schools, and it was felt that the experience of this committee, as well as the very extensive background among its members in the field of giftedness, should be made more generally available. The present volume draws upon this experience and background and offers suggestions for teachers in their work with able students. These students deserve our most serious consideration, for it is they who will produce a substantial share of the leadership in American science in the coming generation.

This volume is the second in the Bulletin series. The first Bulletin was *Biological Education in American Secondary Schools, 1890-1960,* by Paul DeHart Hurd. The Bulletins are under the editorship of Francis C. Harwood of the American Institute of Biological Sciences, Washington, D.C.

To obtain additional copies of BSCS Bulletins, correspondence should be addressed to Mr. Harwood. For information about the BSCS programs, inquiries should be sent to the undersigned.

Arnold B. Grobman, *Director*
AIBS Biological Sciences
Curriculum Study
University of Colorado
Boulder, Colorado

May 1, 1962

The Committee on Gifted Students

Biological Sciences Curriculum Study

Anne Roe
Evelyn Morholt
Hubert Goodrich
Richard Lewontin
Jerome Metzner
Walter Rosen
Paul F. Brandwein, Chairman

PREFACE

All our future investigators in science go through the secondary schools. Clearly, they are a product of their heredity and environment—home, community, school. Studies show that very often a teacher is the "key figure" who plays a significant role in the development of the investigator.

This volume and the companion ones, *High School Biology: Biological Investigations for Secondary School Students*, Volume I and Volume II, have been prepared for use by teachers who are engaged in guiding the young investigator. We believe the art of investigation needs cultivating early. How else will students discover whether the art of the investigator is to be central to their life's work?

Paul F. Brandwein, *Chairman*
Committee on Gifted Students
AIBS Biological Sciences
Curriculum Study

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I

The Creative Student in the Classroom

Anne Roe*†

THE CREATIVE scientist can be identified by what he has done, and is doing. It is not so easy to identify children who have the potentiality to become creative scientists, nor do we know enough to ensure that even if we could identify those with potential, we could help them to actualize it. We do not need here to demonstrate how urgent it is that we learn more about the identification and development of those with such capacities, and that we do so rapidly. What do we know about finding and helping these children?

Perhaps a good way to start is by asking whether there are any personal attributes that are characteristic of mature scientists which might also be characteristic of potential scientists, and whether there are any recurring patterns in the life histories of scientists that might suggest the possibility of such potential in children who behave in similar ways. There have been a number of recent studies of eminent scientists in various fields which have been in quite close agreement in describing natural scientists. They are persons of high intelligence, of marked independence of judgment, disciplined, introspective and sensitive, with intense commitment to their work. They are

*Lecturer in Education and Research Associate, Graduate School of Education, Harvard University.

† Grateful acknowledgement is made for the contributions of many persons to the writing of this essay. Frank Barron, Jacob Getzels, and Paul Torrance acted as consultants from the start. The several drafts were also read and much improved by the comments of Edward Landy, C. Richard Vaughan and Fletcher Watson.

very likely to be so preoccupied with their own thoughts that they may seem quite withdrawn. When they were growing up most of them read intensively and extensively, and many pursued long-term planned projects of various sorts on their own initiative. They may have had one or two close and like-minded friends, and the chances are very good that when they were adolescent they were not social leaders nor even much involved in peer group activities. In school the chances are that they made consistently high grades, but they may have been very erratic in this respect, doing extraordinary work in subjects which interested them, and wilfully neglecting others. They may have been the delight of their teachers throughout school, or they may have been a trial to almost everyone. Clearly they don't match the stereotype of the "clean-cut American boy."

Let us look at the implications of these studies for us. We know that a very small percentage of the students with high academic performance will become research scientists, and certainly not all of the difficult students will. How many others of either group could have made major scientific contributions if something (perhaps a teacher) had been different we do not know, but the possibility of failure or inadequacy on our part is one that haunts us.

Clearly, the scientist-to-be must be intelligent above the average. But this is not a simple matter. Recent studies have developed our concept of intelligence far beyond that of a single, unitary, unchanging attribute. While we have not reached consensus upon the nature and number of factors of intelligence, there is general agreement upon a few, such as verbal, numerical, and spatial, and good evidence for many others. Skill in manipulation and comprehension of verbal symbols is probably the most prominent factor in scholastic aptitude, and needs to be at a superior level for scientific work, but it may be lower in any given individual than such other factors as numerical or spatial ones. With the heavy emphasis on verbal skills which characterize our educational procedures, there is a real danger that children with very high non-verbal skills but relatively poorer verbal ones may be underestimated, particularly if they are in a generally high level verbal group. Indeed, it is quite characteristic of experimental physicists, for example, that their numerical and spatial abilities may be much higher than their verbal ones.

> Most of you must have met such a boy as Hugh. His written work was sloppy, his spelling deplorable, and he was completely uninterested in any improvement in these skills. Yet he was in the 99th percentile on any standard mathematics test, and he not only wanted to be a physicist but had an effective laboratory at home. Considerable sympathetic guidance was needed to persuade him that he must be able to communicate verbally as well as mathematically, not only to get into and through college, but in order to advance in his chosen profession, as he has.

Not every such child is fortunate enough to have a teacher willing to make the effort, but most of these potentially productive students can listen to reason, and are willing to go part way at least. A little later on, we will discuss some of the reasons for resistance to socialization on their part.

A high level of intelligence does not at all ensure creative behavior, which seems to involve quite different factors. There are three recent studies which have compared children on both creativity and IQ, and all have found essentially the same picture of differences. Getzels and Jackson at Chicago and Torrance and others at Minnesota have measured children in elementary and secondary schools on both creativity and IQ. Their measures for creativity included mostly tests specially devised for this such as:

> Use of common objects: list as many different uses as possible for such common objects as tin can, paper clip, brick, etc.
>
> Improvement: list all the ways you can think of to improve a toy dog so that children would have more fun with it.
>
> Fables: compose three different endings for each of several fables, one moralistic, one humorous, and one sad.
>
> Make-up problems: list as many problems as you can think of that might grow out of having an extremely permissive high school principal.

Groups of children in the top 20% of their classes in one or the other but not both[1] were selected for comparison. Although in both studies the difference in IQ means of the groups compared was more than 20, there was no significant difference in any of the measures of scholastic achievement. With the effects of intelligence partialled out, correlations of creativity with all achievement measures were significant.

The National Merit Scholarship Corporation has recently reported a study of the relation between creative and academic performance among talented adolescents. They used a one-sixth random sample of the Finalists in their 1959 program. The 75 variables included grades, tests, self and teacher ratings, originality measures, student's vocational interests and aspirations and information about his background, and his parents' attitudes. High school grades were the criterion for academic performance. Creative performance was defined as "a performance which is accorded public recognition through awards, prizes or publications, and which may therefore be assumed to have cultural value." Examples are: winning science talent search awards, having scientific papers published or presenting them at meetings, winning awards in art, creative writing, or speech contests. The results showed the three kinds of performance (scientific, artistic, and academic) to be associated with somewhat different variables.

> "The boy with a high score on the Creative Science Scale has many artistic achievements and creative activities, plans to get an advanced degree, is a first-born or an only child, and has high scores on the Independence of Judgment, Mastery, Deferred Gratification, Initiative, Physical Activity, and Intellectuality scales and low scores on the Responsibility and Status scales. He rates himself high on originality, independence, and perseverance. Fathers of boys high on scientific performance regard curiosity as a valuable trait for their sons to have; mothers of these boys

[1] About 70% of the top 20% on creativity would have been excluded from gifted groups selected only on the basis of IQ but they were generally well above average. Groups of students in the top 20% of both seem more like the high IQ groups, in general behavior and attitudes.

tend to be agreeable (supposedly comfortable in their role as mothers) rather than irritable. . . . The variables related to academic performance are somewhat different from those related to creative performance. Academic performance (high school rank) is negatively correlated with high scores on the Complexity-Simplicity, Independence of Judgment, and Barron Originality scales and positively correlated with high scores on the Mastery, Deferred Gratification, Self-Evaluation, Self-Assurance, Control, and Status scales. Boys who get good grades rate themselves high on Popularity, Drive to Achieve, Self-Confidence, and Perseverance, and their teachers rate them high on Citizenship, Popularity, and Social Leadership. Fathers of these students want their sons to become good students and are less concerned with their being independent and self-reliant. Mothers of these boys tend to be authoritarian. . . . The findings for girls were similar to those for boys."

Like the studies cited earlier it was found that only 5% to 24% of the students who were in the top 20% on the scholastic aptitude test, verbal or mathematical, also were in the most creative group (top 16% to 18%).

The Chicago and Minnesota studies also investigated the aspirations and attitudes of these two groups of children and found them quite different in these respects. Various kinds of rating scales were used for this purpose. Much more than the others, the creative children value energy, character, purposive striving, a wide range of interests, and emotional stability. Perhaps the greatest difference in their attitudes is the extremely high value they place upon a sense of humor, and they show a considerably greater one in the stories they construct as well as much more originality in all of their work.

In response to a request to make up a story about a given picture, the originality and sense of humor of the high creative group is seen clearly. The examples are for a picture usually interpreted as a man in an airplane returning from a business trip.

The high IQ child: "Mr. Smith is on his way home from a successful business trip. He is very happy and he is thinking about his wonderful family and how glad he will be to see them again. He can picture it, about an hour from now, his plane landing at the airport and Mrs. Smith and their three children all there welcoming him home again."

> The high Creative subject: "This man is flying back from Reno where he has just won a divorce from his wife. He couldn't stand to live with her any more, he told the judge, because she wore so much cold cream on her face at night that her head would skid across the pillow and hit him in the head. He is now contemplating a new skid-proof face cream."
>
> Originality may appear also in handling assignments. Charles, for example, is a student in an enriched biology program. The class made a field trip to a Board of Health, and the report called for was the culmination of the entire course of study for the year. All the students except Charles made about average reports similar to a play-by-play report on a ball game—showing superior knowledge but not deviating from the expected. However, Charles related the entire year's work and the field trip to the part such knowledge played in the experiences and situations of a fictitious family the members of which were given names, personalities, physical traits, and other characteristics necessary to explain their reactions to the normal sequence of events. He then developed situations not uncommon to most families and proceeded to show the effect of the Board of Health in relieving these conditions and the part his course contributed to his own understanding.

The kind of person the creative child wants to be is not the kind of person he believes his teachers consider ideal and likely to succeed in our culture, whereas the high IQ but non-creative child tends to have the same ideals his teachers have. More specifically the high IQ child is likely to be well-mannered, cooperative with teacher and classmates and respectful to his elders. His vocational aspirations will be high level but commonplace. The creative child may also be like this, but he may also be sloppy, undisciplined, eccentric in dress, uncooperative, despising team spirit and class and athletic activities or being merely indifferent to them. His vocational and personal aspirations are not likely to embrace primarily an executive suburban existence or even a conventional professional one.

Getzels and Jackson found that teachers showed a very strong preference for the high IQ groups, in spite of the equally high scholastic performance of the high creative groups. It is easy to understand why. The high IQ groups are much more amenable persons; they believe what they are told; they do not raise difficult questions; they are "well-behaved" and more thoughtful of others; they do not have odd ideas, or disrupting humor. The more creative children have a reputation for having wild or silly ideas; they are very likely to have little consideration for the group and little identification with it, and often resist leadership attempts. This does not endear them to their classmates either. They can be quite difficult, even objectionable, and to a considerable extent they may bring upon themselves the negative sanctions so often imposed on them. Much of their behavior may be motivated by the overriding necessity to maintain their own independence of judgment and this can lead to forms of behavior that are objectionable to others. It is little wonder that most teachers prefer the intelligent but less creative student. This is a serious matter when selection of students for scholarships and other rewards may depend heavily upon teachers' recommendations, and it may have more serious repercussions. Adequate socialization becomes more difficult with increasing age.

An example is Steve, who has an approximate IQ of 140 and superior college entrance examination scores. He is unpopular, has a limited number of friends and is truly obnoxious to most of his teachers because of his general non-conformity. He does extremely well in any area of learning he chooses. His chief concern is mathematics, and as a junior he is doing advanced college work in calculus. His extensive home library contains chiefly mathematics and science, including science fiction. The teachers' reactions to Steve vary with their ability and understanding of gifted students. Many appear frustrated because he causes them to be uneasy and extend themselves and because he is apt to disrupt the class. Other teachers have no trouble because they allow him to progress at his own speed and level. Given this opportunity, while at the same time remaining part of the group, seems to be the answer to this boy's problems in class. And he is fortunate in being able to work after school on occasion with an understanding teacher (but one who does not have him in class) who finds his presence often stimulating and refreshing.

The student who has both high intelligence and high creativity is usually not hard to spot. In general his behavior is rather more likely to be like the high IQ child than like the highly creative child. Perhaps for that reason they are usually liked by their teachers and classmates, and may be leaders in school affairs. They do not introduce many special problems for the teacher, but perhaps they need to be encouraged to exercise their creative gifts more freely than they sometimes do.

How is the teacher to distinguish between the creative student with high potential, and the screwball without it? For science, intelligence well above average is also necessary. And there are other indicators—curiosity, open-mindedness and questioning, originality which sometimes appears as a surge of wacky ideas, independence of judgment, and humor. Even at these early ages, what may be termed a "disposition to commitment," the ability and habit of putting all of oneself into some problem of one's own choosing, can sometimes be seen. This kind of inner-motivated persistence in pursuing individual interests may be a significant indicator, especially when the same interest continues over a long period, and activities follow some plan. If, in addition, the student is willing to discipline himself (or can learn to under guidance) and to submit his ideas to careful check, he deserves all the help he can get.

It is characteristic of an effective scientist that he will work hardest on problems of his own choosing and will withdraw from tasks set for him if it seems necessary in the interests of autonomy. It is also characteristic that he is not above being crotchety when crossed in his attempt to pursue his work, and that he is more likely to question casual authority than to accept it. The same kinds of behavior occur with creative and gifted students but the teacher has a specific responsibility in reacting to them. That the teacher may be the final or more decisive element in the eventual recruitment for science of these youngsters has been frequently demonstrated, both in statistical analyses of the factors reported as influencing students and established scientists, but also in many biographical reports such as that of a well-known Nobel prize winner:

> "I grew up on a farm and thought I'd be a farmer. In high school I was interested in physics and chemistry and I suppose the biggest influ-

ence in high school was a particular teacher who taught physics and chemistry and who was, well I guess she didn't know too much, but she was a very good teacher. She used to let us work after hours in the lab and fool around and it's a wonder we didn't blow things up. She thought I should go to college. I wasn't hard to convince although my father was."

The need for independence is one of the essential characteristics of a scientist, and much of the behavior of the creative adolescent who is difficult is essentially a result of the strength of this need in him, and his sometimes desperate efforts to achieve and protect his autonomy. To many adolescents it is not clear that some degree of behavioral conformity need not at all interfere with freedom of thought, but that, on the contrary, insistence on non-conformity in unimportant details of living can in the long run interfere seriously with getting into a position in which one can do the work he wants. No one can so effectively make this clear as a teacher who understands the problem, and who approves the need for independence, but who can also help to show the reasons for social cooperation, to at least a minimal degree, and for meeting minimal academic and community requirements. The reasons adduced must be valid, but most of these promising youngsters react well to open and just treatment.

In addition to such general standards, there is also the fact that the young student is in no position to know what knowledge, or even what kinds of knowledge, may be important for him in the future, and refusal to study more than just what immediately interests him may hamper him forever. He has to learn, too, that vast amounts of intrinsically uninteresting work are required of every scientist, and he must learn further the vital necessity for verification, for testing his ideas against reality. It is not enough to have new ideas.

John is an example of a brilliant student who wanted to spend all his time on biology, and was not interested in physics, mathematics or anything else, and strongly resisted efforts to persuade him to learn something of these disciplines. His teacher finally took him to a university library one afternoon and showed him some new research papers. He was quick to grasp the extent to which modern work, even in "classical" botany and zoology, depends on statistics and that the instruments used in biological research are based on physical principles.

School subjects differ in the proportion in each of elements which need to be learned exactly, because of the agreed conventions of society, and of elements which can allow for individual variation. We can think of this as a continuum with arithmetic and spelling as examples at one end with a high proportion of conventional elements and artistic endeavor or research as examples at the other end. Even at the creative end of the continuum, however, there are always some conventional elements to be learned by rote. The conventional elements are relatively easily taught and furthermore it is very easy to discover how well they have been learned (which simplifies many aspects of a teacher's job). Unfortunately it can easily happen that in attempting rigorously to educate in the necessary conventions we also educate out creativity.

One difficulty is that it is easy to assume that everything in the curriculum can be taught. Many teachers believe that all learning and thinking is rational or role-related like spelling or the multiplication tables in which the creative or personality-related elements only get in the way. Thus spelling and number facts, problem-solving and experiments, speculative and artistic effort all become assimilated to a single image of rationality in school-work. But the kind of reorganization of experience and the kind of new perceptions of reality that we wish to foster require a different image of school-work.

The problem for the teacher is one of not overconcentrating on the conventional, definable material. This may be a very real problem if only because his own training has very likely been like that. But also there may be an emotional problem here. The teacher who is not very secure can take refuge in repeatable "facts"; he knows the answers in the back of the book and he can usually keep ahead of his students. It is understandably very difficult for most of us to admit how much we don't know, or to face with equanimity the personal challenge that the questioning of a bright, unsatisfied student can seem to present. The teacher whose attitude is one of joy in ongoing learning for himself as well as for his students, and who has long since lost the need to think of himself as all-wise or all-knowing, will not react defensively or personally, but will take up such questions as a shared incentive to new learning.

We should note, too, that it is not only the original student who gets into difficulties. You will not be surprised to know that a recent study has shown that teachers who scored high on ingenuity did not get high ratings from their principals and supervisors.

While sensitivity to problems, curiosity, originality, imaginativeness, cannot be taught, they can surely be fostered. They require from the teacher a permissiveness toward good thinking, which need not mean a similar permissiveness toward behavior. They also demand from the teacher the ability to create an atmosphere in which new ideas are welcomed, and found enjoyable. He may stimulate productive thinking from students by asking dramatic questions: "What might happen if gravity suddenly ceased to function? What effect would result if snow were black? What if there had been no bridge across the Bering Straits? . . ." In such an atmosphere, *every* student, not just the most gifted ones, has a chance to speak out.

Intensity of commitment to science is another characteristic that cannot be taught, but here, as in all matters we have discussed, personal models play a major role. These models may be contemporary or historic persons, of course, but the closer to the student the more effective the model is likely to be. Creative students respond most of all to intensity of commitment in their teacher. This does not mean that to be effective the teacher must be a research scientist. It does mean that the best teachers are people who are obviously in love with the subject they are teaching, and communicate a sense of the fun and challenge in it, as well as its genuine value.

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II

Promising Practices with Capable Students in Biology

Jerome Metzner*

WE ARE CONCERNED here with particular practices that show promise in guiding the development of students of high ability in biology.

Some Useful Approaches to the Identification of Capable Students

There is no certain way of identifying students who have that spectrum of abilities, interests, skills, and psycho-social attributes that might indicate "giftedness" in general, or "giftedness" in a specific area such as biology (see Ch V). *No single technique has been devised that will identify students who are gifted in biology, or other science, with complete accuracy or reliability.*

Objective means such as standardized intelligence tests, achievement tests, and aptitude tests have been used in selecting capable students. Often the results reveal ability that might otherwise have remained hidden. To check the referrals made by teachers and counselors many schools use the *Iowa Tests of Educational Development,* a battery of generalized achievement tests measuring learnings in eight major fields. The results identify young people in the upper 25% on national norms. Lyle Spencer of Science Research Associates has described a mass testing program, undertaken in Oklahoma (11), in which

*Chairman, Department of Biology, Francis Lewis High School, New York City; Lecturer, Graduate School of Education, City College of New York.

the Iowa Tests were given to 60,000 students in grades 9 to 12 in 1 day. Registration in science courses increased as much as 27% following the initiation of this testing and guidance program. Spencer believes that, in order to identify science potential early enough, a testing program should go down to the seventh, and probably to lower grades.[1]

Judgments of teachers and parents, although subjective, may be useful. We refer to such judgments as course grades and information relating to pupils' personality traits, skills, interests, and habits. Judgments of parents (obtained through interview or questionnaire) often help the school to discover interests and capacities that students reveal at home but not necessarily in school; they may include some of the qualities listed below. Along with cumulative records, these afford a means for appraising the many factors contributing to success in selecting and guiding able students.

The following indications of interest in science have been found helpful in identifying science talent (also see page 17).

1. Participating in science-club activities.
2. Using leisure time for science hobbies.
3. Reading scientific literature beyond the demands of school assignments.
4. Participating in science fairs and other contests.
5. Volunteering to undertake special science reports or projects in connection with class work.
6. Attending meetings of junior and adult science societies in the community.
7. Visiting scientific institutions such as museums, botanic and zoological gardens, industrial plants, and research laboratories.
8. Using parents' allowance and gift money for the purchase of scientific materials and books.
9. Exploring and collecting objects of biological, geological, or ecological interest.
10. Indicating aspirations and setting goals toward a career in science.

[1] For a discussion of problems in testing and guidance in science, see *Identification and Guidance of Able Students,* American Association for the Advancement of Science, Washington, D.C., 1958.

It seems clear that identification, if it is to be effective, should be a continuous and flexible process, permitting reconsideration of a student's status or classification as additional relevant information about him becomes available in his school career.[2]

Does identification necessarily involve the procedures that have been mentioned? Not necessarily. Experienced, sensitive teachers frequently have the ability to recognize the gifted among their students by observing such characteristics as those described by Brandwein (1). Observations begun in 1941, and continued at Forest Hills High School (New York City), of the behavioral characteristics of exceptionally capable students, led Brandwein to speculate that there seem to be at least three sets of factors that contribute to the identification of science talented students. These he has called: the genetic, the predisposing, and the activating factors. Admittedly, these terms were used descriptively--to delimit a spectrum of characteristics—and were not categories per se. While general high ability is probably genetically determined, it is highly developed in individuals who are in an environment that permits optimal expression of this ability. Along with high intelligence, high verbal and mathematical abilities are characteristic of those who devote themselves to scientific research, and these are probably genetically based. Genetic factors also include adequate neuromuscular control and adequate vision.

Predisposing factors are described by Brandwein as a persistence in pursuit of one's science interest and questing for explanations, other than those presently given, of aspects of reality. Persistence is described as a strong willingness to spend time, beyond that scheduled, for working on or completing a given task. It is a willingness to withstand discomfort, such as fatigue, strain, or minor colds while performing the task. Questing is manifested by continued dissatisfactions with the explanations of the way the world works. Questing, then, is a purposeful

[2] Many examples of methods of selecting students are described in *Practical Programs for the Gifted* (8).

activity of a student deriving from his scepticisms and dissatisfactions.

Activating factors relate to opportunities in the home or school environment of the child. Are parents interested in their child's studies, and are there also interested science teachers? In the absence of these activating factors, a student may not realize his potential for science but may direct his abilities and energies to fields of interest other than science.

Brandwein adds one other behavioral characteristic of the science prone—a tendency toward introversion. Individuals appear to be more quiet, reflective, and inward looking than the norm.

William Cooley (2), using data provided by Brandwein, concluded that there is no single entity that may be called *science ability*. Aptitude for science appears to be a function of previous scholastic achievement and general intelligence. Cooley indicates that the most reasonable approach at this time is self-identification with free flow in or out of any given program for the talented; individual guidance then plays an important role whenever reliable information becomes available.

At times something happens to a previously nondescript, undistinguished student, something psychological or developmental, resulting in the student's discovery of his own special abilities. He may focus these abilities, sooner or later, on an area of study that interests him more than any other, and from which he derives tremendous satisfaction. This area may be biology. And the phenomenon can be called self-identification.

Original and creative students whose attributes and behavioral characteristics often escape identification are described by Roe (see Ch I). Their giftedness may be obscured by environmental or by emotional difficulties. Some students are identified as being gifted, but, for various reasons, they do not respond to efforts at motivating them to achieve at a level of which they are capable. Recent thought and investigations on underachievement of superior and talented students have been well summarized by Robert Daniel (13, Ch 22), Gwyn Lile (13, Ch 20), and Fred Strodtbeck (9). These underachievers constitute a challenging problem to educators and a devastating loss to society.

Definitions of giftedness, talent, and talented performance vary (13, Ch 3) (9, Ch I). For those who seek some guide, the following selective practices may be helpful. The Educational Policies Commission has suggested that highly gifted students have IQ's of 137 or more; those with IQ's between 120 and 136 are considered moderately gifted. Some school systems, such as that of Denver, Colorado, have begun the identification of gifted in the kindergarten, and efforts are made to identify numbers of gifted students by the end of the third grade. In Palo Alto, California, identification begins after the fourth grade, while in Evanston, Illinois, the search is initiated in the junior high school.

Jack Kough and Robert DeHaan (6, Ch 6) (7, Ch 5) have summarized the characteristics of a student possessing high ability in science:

1. Expresses himself clearly and accurately either through writing or in speaking.
2. Reads 1 or 2 years ahead of his class.
3. Is 1 or 2 years ahead of his class in mathematical ability.
4. Has greater than average ability to grasp abstract concepts and see abstract relationships.
5. Has good motor coordination, especially eye-hand coordination. Can do precise manipulations.
6. Is willing to spend time beyond the ordinary assignments.
7. Is not easily discouraged by failure of experiments or projects.
8. Wants to know the reasons for things.
9. Spends most of his free time on special projects of his own, such as making collections, constructing a radio, making a telescope.
10. Reads a good deal of scientific literature and finds satisfaction in thinking about and discussing scientific affairs.

The Capable Student and Biology

Some indication of how gifted students may be identified has been given. But, how are those able or gifted in biology identified?

The gifted or able biology student may be recognized as one who shows a deep involvement in some area, some problem in the biological sciences. Briefly, he works well and he works hard and long. Many teachers of biology have met students like the ones described in the examples given here.

> After reading about conjugation in *Paramecium* and in *Spirogyra* a student ponders on a problem such as: How is it possible for two *Spirogyra* cells to have their contents enclosed within the walls of one cell after conjugation? He reads in Smith's *Fresh Water Algae of the United States* and learns about Lloyd's discovery of the development of small contractile vacuoles in the protoplasts of conjugating *Spirogyra* cells. He is intrigued by the fact that although conjugating cells of *Paramecium* and *Spirogyra* look alike they have different physiological qualities. His persistence in finding out more about this aspect of sexuality leads him to the studies by Tracy Sonneborn on mating types of *Paramecium*.

At times, students raise questions that reveal a profound conceptual understanding transcending that of their peers. For example:

> During a class discussion centering on the functions of the macronucleus and micronucleus of *Paramecium*, a student may ask whether both of these contain chromosomes; whether there are special chromosomes in the micronucleus associated with reproduction and others in the macronucleus associated with cell metabolism. Or, after learning about the role of the contractile vacuole in maintaining water balance in various protozoa, a student asks how it is possible for water to move from a region of lower water concentration in the cytoplasm to a region of greater water concentration inside the vacuole when this seems contrary to the laws of diffusion.

At other times, a student finds an intriguing problem for which he cannot find an answer, even after a diligent search of the available literature. He discusses the problem with his biology teacher who, after giving all the help he can, refers him to a local university professor working in the field relating to this problem. Or, if there is no local university, the teacher helps by suggesting names of scientists with whom he might correspond.[3] After acquiring background and suggestions from various people, the able student designs an experimental procedure and puts this to a test in the laboratory.

Essentially, the teacher should match his students' gifts with opportunities. Schools need to give opportunities to students of varying abilities.

The Teacher of Capable Students in Biology

Much of the success achieved in the practices and the programs described below is predicated on the competence of the teacher. How competent in biology should a teacher of the gifted be? How capable a teacher must he be? It is difficult to answer these questions because so much depends on the personality of the teacher and on the demands made upon him by his students. French (4) states that the most frequently listed characteristics of the teacher of the gifted are: high intelligence, special aptitudes, deep knowledge of his own field, broad knowledge of related fields, knowledge of teaching techniques, flexibility, creativity, and acceptance of student ideas. Davis (3) stresses the point that, along with other characteristics, the teacher should have a capacity to encourage specific qualities of the gifted and channel them into worthwhile learning experiences. He must understand their characteristics and know how to encourage them to assume responsibility and take initiative.

Brandwein (1) studied the characteristics of some 82 teachers who inspired youngsters on the high school level to commit themselves to a career in science. He found that 90% of these

[3] For example, he and his teacher might examine current issues of *Biological Abstracts;* or they may write to the Society of American Bacteriologists, to the American Institute of Biological Sciences, or to the American Association for the Advancement of Science.

teachers had a Master's Degree in Science (in addition to required work in education) and had also published at least one paper in science or education. All were in good health, had some hobbies, and were vigorous in their personal manner, that is, they were people who possessed decisiveness. He noted that these teachers were "not only admired and respected as teachers of subject matter, but as teachers in the ways of life. They were guides, counselors, friends, guardians, father-confessors." To Brandwein it was abundantly clear that these teachers "held up to their students firm standards of competence in scholarship as well as in behavior."

In *Origins of American Scientists* (5), Knapp and Goodrich describe in detail a similar set of characteristics of effective teachers at the college level.

Other studies present similar findings (13:265–286) (14). Although a thorough knowledge of biology and a working knowledge of the related fields of chemistry, physics, mathematics, and earth science are desirable, it is difficult for the teacher to attain competence in these broad cultural and scientific areas in his undergraduate and graduate training before his teaching career begins. There is, therefore, a need for continued, ongoing education in biology for the teacher, especially the teacher of gifted students. This need may be met through in-service courses taken as institute or university courses. By consistent reading of scientific literature, by attending meetings of scientific societies, or by engaging in research projects, the teacher increases his own competence in science. These experiences help to extend the teacher's background knowledge of subject matter and bring him up to date.

In addition to good scholarship, a teacher of the gifted is usually an expert teacher. He keeps himself informed on new developments in teaching biology through reading professional literature, attending professional meetings, and exchanging ideas with fellow teachers. He continuously searches for or invents better ways of teaching.

The most desirable teaching techniques to use with gifted students are basically the same methods employed in helping students of all levels of ability. Some effective methods are described below.[4] Their value mainly consists in allowing an individual student to assume an increasing degree of responsibility for his own learning and to work according to his abilities and interests. Frequently, a teacher's assignments give the able students more opportunity to take on responsibility for answering optional questions of a higher order of complexity and challenge than the required assignment—to go beyond the high school text and use college texts, references, and science journals in their explorations.

A teacher with five biology classes (or other preparations) may have limited opportunity to organize laboratory work and to prepare materials for it. He is forced by practical considerations to resort at times to demonstrations. How can he be more effective in the time allotted for laboratory investigation?

One solution to this problem has been instituted by the New York City schools where laboratory assistants are used. These assistants are assigned to biology departments (also to departments of chemistry and physics) on the basis of the number of biology classes, but there is at least one assistant in each biology department.

The duties of the laboratory assistant include: the preparation of materials for daily class and laboratory work, as well as for teacher demonstrations; the care and maintenance of laboratory equipment; the preparation of solutions and culture media; the organization of student laboratory aides as squads; mimeographing instructional materials; aiding students in project laboratories; and a miscellany of other responsibilities. Obviously the position of laboratory assistant facilitates the teaching of biology and often releases the teacher so that he can plan instruction more effectively and guide individual students.

[4] Further descriptions of how a teacher works with individual students are presented in Paul Brandwein's paper, Chapter III.

The curricular innovations in biology that are currently under study stress enriched laboratory experiences for all students and suggest opportunity for intensive and extensive laboratory experience, as well as original investigations, for able students. To make this possible, the position of laboratory assistant seems to be almost indispensable.

The Grouping of Capable Students in Biology

Those concerned with science education in our country are currently appraising existing curriculum patterns. This evaluation will undoubtedly result in uplifting course offerings as well as initiating a more frequent adoption of a multi-track curriculum better designed to meet the needs of the variety of children in our schools.

One example of such a study is the work of the Biological Sciences Curriculum Study, sponsored by the American Institute of Biological Sciences. The talents of outstanding college and high school teachers have been enlisted in developing new approaches to the teaching of biology. The objective of this study is to provide a comprehensive course in biology that will stimulate students to work to their fullest capacities. It is hoped that students will acquire a literacy in the fundamental principles and conceptual schemes of biology and also begin to approach current problems in biology. Specially designed laboratory work has been suggested as one way to aid in the identification of able and gifted students in biology.[5]

It would be difficult and probably undesirable to attempt to specify the nature of the curricular activities in biology that are offered to highly capable students. In any given situation there may be many limiting factors, such as size of the school, training and experience of the biology teacher, facili-

[5] Apart from carefully planned laboratory work, a series of laboratory "blocks" have been developed by the BSCS (see p. 33). The Investigations submitted by biologists and edited by the Gifted Student Committee are intended for individual research extending over a year or two in high school.

ties and materials for instruction in biology, and understanding, sympathy, cooperation and support of school administrators and the community. Each school or school system will, it is hoped, develop procedures that meet the specific concerns of their students and the community.

Kough (8, Ch 7) gives cogent descriptions of outstanding, ongoing programs for gifted students that are in operation over the country (see also App H). Experts in the field of work with gifted children were asked to nominate effective programs. The school systems selected and described are these:

Chula Vista City School District, Chula Vista, California
Helix High School, Grossmont, California
LaMesa-Spring Valley School District, LaMesa, California
Lemon Grove School District, Lemon Grove, California
Los Angeles City Schools, Los Angeles, California
Palo Alto Unified School District, Palo Alto, California
San Diego City Schools, San Diego, California
Denver Public Schools, Denver, Colorado
Dade County Public Schools, Miami, Florida
Evanston Comm. Consolidated Schools, Evanston, Illinois
Evanston Township High School, Evanston, Illinois
Quincy Public Schools, Quincy, Illinois
New Trier Township High School, Winnetka, Illinois
Indianapolis Elementary Schools, Indianapolis, Indiana
Indianapolis Secondary Schools, Indianapolis, Indiana
Baltimore Public Schools, Baltimore, Maryland
Newton High School, Newtonville, Massachusetts
St. Louis Public Schools, St. Louis, Missouri
University City Elementary Schools, University City, Missouri
University City High School, University City, Missouri
Forest Hills High School, Forest Hills, New York
Lewis County Public Schools, Lyons Falls, New York
Bronx High School of Science, New York City, New York
High School of Music and Art, New York City, New York
Hunter College Elementary Schools, New York City, New York
New York City Elementary Schools, New York, New York
New York City Junior High Schools, New York, New York

New York City Senior High Schools, New York, New York
Bedford Public Schools, Bedford, Ohio
Cincinnati Public Schools, Cincinnati, Ohio
Cleveland Public Schools, Cleveland, Ohio
Portland Public Schools, Portland, Oregon
Cheltenham Township School District, Elkins Park, Pennsylvania
Colfax Elementary School, Pittsburgh, Pennsylvania

Programs and Methods

The administrative devices and school practices that follow have proved useful in many schools with a heterogeneous school population. The basic administrative procedures in use for programming gifted students are these (from 8, Ch 2–5):

I. Classroom enrichment

II. Grouping
- A. Specialized schools
- B. Special classes in regular schools
  1. Classes recruited from one school
  2. Classes recruited from several schools
- C. Special grouping for only part of the school day
  1. Grouping in the curricular areas
     - a. Multitrack programs
     - b. Honors courses
     - c. High school seminars
     - d. Special courses
  2. Grouping for noncurricular school activities
- D. Grouping for out-of-school activities
- E. Grouping within the regular classroom

III. Acceleration
- A. Skipping of grades
- B. Early admission to the education program
  1. Early admission to kindergarten or first grade
  2. Early admission to college
- C. More rapid progress through normal educational sequence
  1. Ungraded primary
  2. Two grades combined in one, or three in two

3. Advanced placement program
4. Extra courses for extra credit
5. Credit by examination

Specific Programs

Let us examine some specific cases of grouping.

Honors Classes in Biology

Honors courses, or their equivalent, are offered in many schools. They are usually enriched courses of study that reach to a college level. The kinds of enrichment may vary. There may be a study of modern aspects of biology or a stress on the development of concepts and broad generalizations. For example, the unit on genetics may be enriched by including such topics as microbial genetics with emphasis on the work of Beadle, Tatum, and Lederberg; or in a biochemical approach, the concepts developed may include an interpretation of the energy transfers in cellular metabolism.

One example of an enriched program in biology has been prepared in a series of monographs from the Science Manpower Project of Teachers College, Columbia University. This program stresses modern biology and its interrelationships with other science as well as non-science disciplines.

Additional programs and special activities are described by biology teachers in their STAR (Science Teacher Achievement Recognition Program) reports published by the National Science Teachers Association. They provide illuminating examples of individual work with capable students (see App E).

In general, in honors programs, extra time for laboratory work is provided by adding one or more periods to the traditional school day. Students are encouraged to undertake biology projects or to become involved in co-curricular biology activities and after-school clubs. The science resources of the community are utilized to advantage; the school or the students may draw on local natural land areas, botanical gardens, zoological gardens, museums, industries, biological research organizations, libraries, and scientific personnel of local colleges and universities.[6]

In these honors classes in biology, a freshman college text[7] may be used to supplement or to replace a high school biology text. Furthermore, students are introduced to the many kinds of biological literature such as texts, monographs, journals, reprints, abstracts, and magazines.[8] They learn how to search the literature for special types of information.

The practices that are selected for highly able biology students are aimed toward providing them with an environment in school (and in the community) in which their interests, once stimulated, may be fully nurtured and realized.

Some believe that a simple and effective way to handle the gifted in biology is to have them cover more work. For example, in a study of protozoa, they would have the student make drawings and perhaps models of several kinds of protozoans in addition to *Paramecium* and *Ameba*. In studying evolution, they would have him prepare lengthy reports on the life and work of Darwin. But the gifted, when given freedom and some encouragement, will go far beyond this level of operation. They will delve into the structure and function of protozoan motor mechanisms, for instance, or the effects of environmental factors on growth rates of protozoa, or the nature of the killer factor in *Paramecium*. They will tackle with enthusiasm the interpretation of the latest findings in the broad field of evolution

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[6] A description of one seminar given at New York Botanical Gardens is given in Appendix I; an example of a seminar program in which industry and the community resources are utilized is the Joe Berg Foundation program detailed in Appendix G. The Dade County, Florida, program of evening seminars is another example, page 38.

[7] *Life* by G. G. Simpson, C. S. Pittendrigh, L. H. Tiffany, Harcourt, Brace and Co.; *Principles of Modern Biology* by D. Marsland, H. Holt; *The Science of Biology* by P. Weisz, McGraw Hill; *The Biotic World and Man*, L. J. Milne and M. Milne, Prentice Hall.

[8] See Chapter IV for bibliography of periodicals and references in biological sciences.

(for example, the significance of *Oreopithecus, Australopithecus,* and *Proconsul*), and they will discuss modern theories of evolution intelligently, referring to the works of Dobzhansky, Muller, Simpson, and others. It is probably more profitable for the gifted to discover deeper understandings that will bring them to higher conceptual levels than to be engaged in covering more laboratory work that repeats what is covered in texts or manuals. Surely some techniques must be polished through practice, but most beneficial are problems that stretch ability and competence.

Advanced Courses

Some schools have recognized that gifted, as well as able students, may undertake a heavier academic load than those of more average ability. Such students have been offered five, and even six major subjects. This arrangement has made it possible to offer advanced courses in science, including advanced courses in biology, without displacing basic biology from its usual 10th year position. Other schools, lacking these arrangements, sometimes offer enriched biology courses in the 9th grade to gifted students, and then offer chemistry and physics in the 10th and 11th years with an opportunity for the students to take an advanced placement course in one of the sciences in the 12th year.

A school like Evanston Township High School has a long history of advanced courses at the college level for able students; it was a pilot school in early experimentation with the Advanced Placement Program. Grouped in a science seminar in the last 2 years of high school, able students engage in research projects of their own (see App F, G). Other programs for capable students in science are well described in *Science for the Academically Talented,* prepared by NEA and NSTA. 1959. Washington, D.C.

Several other modifications of the science curriculum have been made to find a suitable place for enriched biology courses.

In some schools highly talented students, selected on the basis of achievement in science and interest in biology, are placed in 10th year chemistry classes. Their special chemistry course stresses the fundamental particles of matter, the nature of chemical bonds, energy changes in chemical reactions, and simple organic chemistry relating to biological processes. The honors biology course, taken concurrently or later, is often focused on a biochemical approach.

In a few schools basic chemistry and physics precede advanced biology, which, under these circumstances, includes not only a biochemical approach but also some aspects of elementary biophysics and radiation biology.

Experiments with Advanced Courses

Several kinds of advanced courses in biology, designed for students who are committed to science, are offered in schools where there are sufficient numbers of candidates, adequate facilities, and competent teachers.[9] [10]

Some schools offer experimental biology courses devoted mainly to research carried on by individuals or by small groups and extending from one to several semesters. Examples of kinds of problems that students undertake can be gleaned from an examination of the lists of research projects submitted in the annual Future Scientists of America Contest and in the Westinghouse Science Talent Search (see App C). These often show a high level of sophistication and wide range of interests.

1. *Courses in special fields* such as microbiology, field biology, human physiology, plant physiology, history of biology, zoology, given for one or two semesters, afford able students opportunity to pursue advanced study in areas of biology of

[9] Many specific programs for training of teachers and also for in-service study are offered in *Working with Superior Students* (13, 265–286).

[10] Specific courses of an advanced nature are well described in *New Developments in High School Science Teaching*, National Science Teachers Association, Washington, D. C., 1960.

special interest. These offerings provide rich laboratory or field experience, emphasize current research, and help the young student to explore his potential as a scientist.

2. *Seminar courses* do not follow a highly structured syllabus but permit the cooperative selection by students and teachers of special areas in biology, and these topics are studied to a depth consonant with the interests, needs, and abilities of the class.[11] Their value lies in the opportunity they offer for individual and group biological research, for search into the literature relating to a given subject, for preparation and organization of comprehensive reports, for oral reporting to the class, and for the benefits derived from class suggestions and criticisms.

A successful seminar course extending for one or more years and providing for intensive individual and group research in a few biological areas has been given at Melbourne High School in Florida. Teams of students worked on problems relating to amphibian development, endocrinology, and genetics of *Neurospora*. All members of a team worked in the same general area, but each student had a specific individual problem. Throughout the year students made a competent search of scientific literature and thus developed an awareness of the present state of knowledge in their chosen area. In weekly or bi-weekly seminars, students gave reports on the scientific literature as well as progress reports on their own research. Professional consultants were invited when special help was needed.

Junior seminars in medical science were sponsored by doctors, educators, and YMCA officials in Pasadena, California. The purpose was to give promising students an authentic picture of medicine and applied science and to stimulate their interest in careers in these fields. The program involved the participation of 20 medical doctors, the University of Southern California Medical School, hospitals, research institutes, the schools,

[11] See the seminar topics in a program like the ones described in Appendix F and G.

and the YMCA. The seminar organization included lectures on medical problems, field trips to medical hospitals and laboratories, the showing of new films on particular aspects of medicine, and a study of related problems illustrating the work of doctors. Participating students were chosen on a quota basis from individual schools in the city after a screening process selected those most interested and qualified.

Many seminars have been established where students from small schools are invited as a group to attend meetings at a college. For instance, Oneonta State Teachers College holds special seminars in science, mathematics, and humanities.

3. *College Level Courses: Advanced Standing.* With the recognition that able high school students, allowed to proceed according to their abilities, are capable of college-level work, many high schools offer college courses in biology under arrangements made with the School and College Study of Admission with Advanced Standing.[12] These arrangements permit local modifications of a basic college biology course recommended by the high school and college teachers' committee on biology. They are rigorous college courses rather than enriched or upgraded high school biology courses. As advanced standing courses, they are usually offered to selected 12th grade students who have shown high achievement in biology and have had a basic course in chemistry and/or physics. Some schools have gone well beyond the outlines of the standard Advanced Placement course by stressing a biochemical approach, modern principles of biology, and current biological research.

The high school teachers giving these courses are usually selected from those who have increased their competence by taking appropriate courses in institutes, colleges, or universities.

Many colleges offer high school students both college credit and advanced placement; others give advanced placement only. By virtue of having begun college work in high school, the

[12] Descriptive material may be obtained from the College Entrance Examination Board, 425 W. 117 St., N.Y. 27, N.Y.

preparation time necessary for graduate studies in biology has been shortened for many able students in this program.

4. *College Classes.* Arrangements between colleges and high schools are enabling highly capable high school students to attend college biology classes on Saturdays, during part of the regular school day, or in summer sessions. The arrangement between the Portland, Oregon Public Schools and Reed College is a well-planned, successful example. Another cooperative program exists between the University of California and local high schools (8:62–72, 134). Students receive college credit or they audit in the courses without credit. Colleges, in some cases, offer selected students the opportunity to earn college credit by passing special examinations. In this way it is possible for an honors biology student to receive credit for knowledge acquired in high school courses or through independent study.

Offerings in Specialized Science High Schools

With the large student population in New York City, for example, it is possible to provide several specialized science high schools—Stuyvesant High School for boys, Brooklyn Technical School for boys, and the Bronx High School of Science for boys and girls.[13] We shall describe the offerings of one, the Bronx High School of Science, although the objectives and the type of entrance requirements of other specialized science high schools are quite similar.

Students are selected from all areas of the city by entrance examinations. They receive a liberal education in the humanities, sciences, and mathematics. Enriched basic courses in biology, chemistry, and physics are required, and students may elect to take one or more advanced courses in a special science.

Gifted biology students (usually identified in the basic 10th year course in biology) receive many opportunities to pursue special interests in advanced work in microbiology, field biology,

[13] There are also specialized schools for music and art, for performing arts, and for special trades in New York City.

experimental biology, or physiology. Upon the recommendation of his biology teacher, a student may work in the biology project laboratory where, under teacher guidance, he pursues a research problem. His work in the project laboratory may extend from the sophomore through the senior year.

Most often students, who become interested in some phase of biology while they are taking the basic course, begin with a relatively simple problem, which may lead to increasing orders of complexity by the time that they are Seniors. One student, for example, developed a strong interest in the components of blood. After considerable library work, he obtained and studied samples of blood of common vertebrates. Later he became interested in research that attempted to correlate the presence or absence of various plasma constituents with certain types of cancer (see p 103). This student eventually became apprenticed to a member of a research team concerned with this approach at the Sloan-Kettering Institute for Cancer Research.

After completing a unit on heredity, another student decided to raise a species of blow fly. His work, patterned on the work done with *Drosophila,* led to his discovery of an unreported mutation, which he described in a publication written in collaboration with a renowned geneticist.[14]

Of course, a specialized high school for science provides a highly favorable physical environment in which science talent may flourish. Its biology facilities include greenhouses; separate laboratories for basic and advanced courses; a project laboratory; an animal room; photographic dark rooms; laboratory preparation rooms where laboratory assistants,[15] aided by student

[14] Similar examples from New York City could be described from Stuyvesant and from some comprehensive high schools like Erasmus Hall and Midwood High Schools in Brooklyn, New York, and Jamaica High School and Forest Hills High School in Queens, New York. Exceptional work has been achieved in Science at Evanston (Illinois) Township High School. (See Topics of Westinghouse Honors Group, Appendix C.)

[15] For a description of the position of laboratory assistant see page 21. Project room facilities are described in Appendix A and B.

laboratory squads, prepare instructional materials for class use; a department library; and a school library with diverse types of publications in biology.

Laboratory and Field Experience. One specialized high school[16] offers an elective course in field biology given for 1 year on a 4–2–1 period per week arrangement. Four consecutive periods, on a given day each week, are devoted to a field trip to a natural area, park, museum, zoo, botanic garden. The two-period session on the following day is usually given over to laboratory study of materials gathered in the field. In the single period there may be class discussion, pupil reports, guest lectures, or planning of the next field trip.[17]

Algae, protozoa, rotifers, water ferns, hydras, and crustaceans, found in pond samples, provide material for many hours of fruitful laboratory study. Slime molds, collected from rotting wood and cultured in the laboratory on artificial media, offer opportunities for controlled experiments with both plasmodial and fruiting stages. Frogs from one or more ponds may be systematically examined, in the laboratory, for the protozoan inhabitants of the large intestine; this provides material for the intensive study of *Opalinids* and *Nyctotherans.*

The adaptations and interrelationships of living things, and their ecological and geographic distribution, are pervasive aspects of biology that can be studied in the field. In the laboratory, students learn the techniques developed by biologists.

Block Laboratory Work

In many schools the traditional type of laboratory work, the following of explicit directions to a foreknown end, has been supplemented, or partially replaced, by open-ended laboratory

16 Bronx High School of Science. Probably several other schools over the country offer similar courses.

17 Other examples of carefully planned activities relating to field and laboratory work are presented in *Laboratory and Field Studies,* edited by C. Lawson and R. Paulson, sponsored by National Academy of Sciences, Holt, Rinehart, Winston, 1960.

work; that is, investigations or problems for which answers are not immediately known but may be discovered through student experimentation.

Examples of investigations done by students reveal that more time is needed for laboratory work. In some schools biology classes are scheduled for three double periods each week. One, or more, of these periods is usually available for laboratory work.

It is difficult to compress into a single—or double—period laboratory the many experiences that emphasize the important features of an experimental approach. Continuity of time and effort in pursuit of a problem is required until the desired outcomes are obtained. In recognition of this problem, Bentley Glass, of Johns Hopkins University, has proposed the use of a block of uninterrupted, consecutive time for student investigations. A committee of the Biological Sciences Curriculum Study has prepared laboratory blocks, each of 5 to 6 weeks duration, titled *Interdependence of Structure and Function, Microbes: Their Growth, Nutrition and Interaction; Plant Growth and Development; Animal Growth and Development.*[18] By way of example, the laboratory block called *Plant Growth and Development* includes the following broad problem areas: measurement of plant growth, germination, internal organization of plants, nutrition, and growth substances. Also included in each area are laboratory experiences dealing with such specific topics as: environmental factors affecting germination, growing areas, cell division, organization of tissues, photosynthesis, mineral nutrition, uptake of ions, starch hydrolysis, respiration, auxins, and tropisms.

Another laboratory block, *Animal Growth and Development*, contains a detailed program for each of 21 school days. Laboratory experiences include: study of amphibian eggs collected in the field, induced ovulation, artificial fertilization and partheno-

[18] These and other Block Laboratory studies are available from BSCS, University of Colorado, Boulder, Coloradc.

genesis, maintaining frog eggs at different temperatures, development of eggs in the absence of oxygen, chemical inhibition of development, regeneration of amphibian tails, role of the thyroid gland and effects of iodine and triiodothyronine in amphibian development, development of the chick embryo, effects of various influences on the chick embryo, and regeneration in planarians.

These blocks are intended for group study with classes of standard size and ability rather than individual student projects. The concern is to present a reasonably penetrating exploration of one selected problem area in order to advance expeditiously toward current work in the field. Only those skills necessary for this purpose are stressed. Nevertheless, these blocks offer extraordinary opportunity for classes of gifted students to probe into problems of an increasing order of complexity and challenge. It may well be that, for the gifted student, the laboratory block will provide the motivation to engage in a related research problem. An objective of the blocks is to give students an appreciation of the need for careful, quantitative observations, for application of inductive and deductive reasoning, and for experimental controls. They learn that conclusions in science are tentative, and they learn the need for suspending judgment. By working in teams, students learn to cooperate in a scientific endeavor.

At the completion of a block, students are often at a point where they can develop their own hypotheses and begin devising experiments to test them. Thus students are acquainted with the nature of scientific investigation and have a feeling of having participated in it.

Different classes of students may be assigned to different blocks conducted at different times during the school year. Each block is best suited for inclusion at a time when the basic subject matter needed as a foundation has been discussed. Some blocks may be more appealing to a teacher than others (or more suitable on the basis of the teacher's background).

Other Activities in Biology Provided by Schools

1. *Student laboratory aides* working within a class period assist teachers and learn how to prepare, distribute, and use laboratory materials and equipment. They may be trained to maintain live plants and animals, collect specimens, and build needed types of equipment. In these activities the student not only gives the school valuable services but also benefits from the special training he receives.

2. *Biology squads,* organized under teacher sponsorship, provide outlet for special interests and give services to the school. Such groups as drosophila squads, protozoa squads, histology squads, scientific-illustration squads, bacteriology squads, and field biology squads have two main activities. They prepare or maintain materials for school use, and in addition, the students in each squad use these materials in their own individual or group projects. While the drosophila squad, for instance, maintains cultures of various types of *Drosophila* for genetic studies in biology classes, one member of the squad may be studying the inheritance of a group of linked factors.

3. *Biology project rooms,* appropriately staffed and equipped (see App A), afford a splendid environment in which gifted students can give expression to their talents and special interests in biology. Here student squads, pupils from basic and elective biology courses, aspirants for science awards—any students with crystallized problems in biology—can find the means for "Sciencing," doing the work of scientists.

4. *A biology journal* provides an outlet for young scientists with literary and illustrative talents to communicate the results of their endeavors to their peers. Student editors gain experience in selecting, editing, and arranging materials for publication in addition to handling business affairs. An interchange of journals among schools in different localities widens the scope of communication and motivation among student scientists.

5. *Biology clubs* are on-going activities for many students with interests in biology. The motivation for organizing a club

may originate with students or teacher, but it is often the degree of inspiration, leadership, understanding, and guidance given by the teacher that spells success or failure of the group. Able students often become leaders in a club.

Some able students arrive at a level of sophistication in their special biology interests that enables them to attend meetings of adult science societies at local academies of science, museums, colleges, and universities. Some adult science societies, in fact, encourage high school students to attend, offering them membership.

6. *Biology field trips* offer students materials and experiences that are not available in the classroom or laboratory. We have already described the advantages of these trips as part of class work (see p 33). Some schools have organized Saturday or Sunday field trips conducted by competent teachers or outside leaders who are compensated for their efforts. In a more ambitious arrangement, one or more weekends are devoted to an organized regimen of field experiences.

7. *Science fairs and congresses* offer opportunity for young investigators to exhibit their work, thereby providing both information and stimulation to other students. Students also derive personal satisfaction and prestige. A young scientist often has opportunity to report the results of his work in an appropriate scientific journal, and perhaps to discuss his results at a convention or academy session of young scientists. Local, regional, and national conventions, patterned on those of professional scientific societies, provide suitable forums.

8. *Honors biology students as tutors.* A limited amount of tutoring by gifted students has proved beneficial to the student being tutored, to the school, and to the student tutor. Tutors are selected on the basis of their interest in teaching and their high level of academic achievement.

9. *Specialists and other community resources.* Probably in every community, large or small, there are specialists in some

area related to biology who are willing to help students interested in their field. A useful device for capitalizing on this assistance is a community resource file where pertinent information, filed under the specialists' names, is recorded. The file may include doctors, veterinarians, dentists, health and sanitation officers, college professors, naturalists, research workers, technicians, hobbyists, and staff members of a museum, zoo, or botanic garden. Specialists may be invited to describe their work to classes, clubs, or assemblies. Some may permit students to visit and to work in their laboratories or to learn to use science equipment. Capable students may be accepted by some as part-time apprentices. Throughout the country more and more practices of this kind are in effect.

This pattern of community-school operation is well illustrated in the program in Dade County, Florida, where a class in scientific research has been organized for seniors specializing in science (8:73–75). The teacher functions as a consultant and liaison between students and faculty members or scientists in the community. In such a project in which school and local research scientists cooperate, students are released from school before the last period of the school day. In this time, and usually for a much longer period, work on a project in neighboring laboratories, in such areas as bacteriology, enzyme chemistry, tissue culture, virology, and microbiology, is under way.

Another program for the advancement of science and the opening of opportunities in industry for able students may be initiated by teachers, administrators, or parents who communicate with the Joe Berg Foundation.[19] Essentially, the plan is national in scope and recommended by the Board of Directors of the National Science Teachers' Association. It calls for the effective use of existing community science resources. It helps schools to establish science seminars thereby providing extracurricular training for selected able students. For this purpose

[19] Examples of the types of seminars conducted by this foundation and details for using the services of this organization are given in Appendix G.

it enlists the cooperation of technologists and professional scientists of the community.

The plan stresses the idea that students with abilities in science deserve the same recognition and support given to athletes in this country. Scientists in the community have also been stimulated by their contact with high school students who have high ability and deep interest in science.

Industries, cognizant of the need for encouraging and training science talent, are very willing to give financial support to programs for gifted biology students (provided they are approached by school representatives with concrete plans and proposals).

Courses in modern biology, as well as scholarships, apprenticeships, research opportunities, the preparation of biological educational materials and equipment, all have received industrial support in different parts of the country. Furthermore, industry has permitted some of its scientists to cooperate in school-community programs for high ability biology students.

Many locally sponsored programs, either given during the summer, after school, or on Saturdays, are well described in *Guidance for the Academically Talented Student,* edited by C. Bish, E. Cotlove, A. Hitchcock, N.E.A., and American Personnel and Guidance Association.[20]

Nationally Sponsored Science Training for Capable Students

1. *National Science Foundation.* All of us are familiar with this program designed to encourage the interests in science of high-ability high school students by providing them with activating situations to match their abilities. Colleges and nonprofit research organizations offer many programs that may take the form of summer institutes for students.

Information about these programs is distributed to secondary schools by the National Science Foundation.

[20] Available from National Education Association, 1201 Sixteenth Street, NW, Washington 6, D.C.

2. *A grant provided by the National Institutes of Health* to a carefully selected group of high school students for equipment, chemicals, and supplies is described by Flavin J. Arseneau of Arlington Heights High School, Fort Worth, Texas. Arseneau describes his thoughtfully planned program, sponsored by the National Cancer Institute, United States Public Health Service, in his entry in STAR (12). Small groups of students work all day Saturdays and during the summer.

3. *Programs supported by industry.* The objectives of the National Merit Scholarship Corporation and of Westinghouse Science Talent Search, among many, are well known. We have culled the titles of honors papers in biology from some of the Westinghouse contestants in Appendix C.

Summer Research for Students

1. *The Roscoe B. Jackson Memorial Laboratory* at Bar Harbor, Maine. This is an effective program based on the principle that students gain skill in scientific research by actually undertaking such work.[21] It aims to find and encourage scientific ability at an early age by bringing science talented boys and girls into contact with research workers, their methods, and the materials they use for investigating problems in science.

The program offers work in genetics, cancer research, and experimental behavior. Students learn to design an experiment, to search the literature, to work on a specific problem, and to write a well-organized paper on some topic in science.

In the main, the students accepted are juniors and seniors, but admission may be granted to exceptionally well-qualified sophomores and freshmen.

2. *The Worcester Foundation for Experimental Biology,* St. Mark's School, Southborough, Massachusetts. This program[22]

[21] Application blanks are available by writing early in February to Dr. John Fuller at the Laboratory.

[22] A catalog is available describing the requirements, date of application (early spring), and details of the courses offered.

also attempts to stimulate gifted biology students, who may later choose science as a career and become leading teachers and investigators, by giving them opportunity to work in a research atmosphere and come into contact with distinguished scientists.

The program is co-educational, spans 9 weeks of the summer, and provides for two groups of students—first-year and advanced. First-year students study introductory material relating to the fields of mammalian anatomy and physiology, with some aspects of pathology. Laboratory work on the mouse and rabbit, correlated with lecture material, emphasizes careful observation of anatomical structure. Introductory lectures on the elements of biochemistry are accompanied by laboratory work during the rest of the summer. Like the program at the Roscoe B. Jackson Laboratory, the students learn, practice, and apply special techniques to a pilot experiment.

Advanced students, usually six of the outstanding first-year students, spend the summer working in the laboratory of a sponsor who is a permanent member of the research staff. Their projects, to be completed by the end of the summer, are planned at a level consonant with the students' abilities and aimed at giving them a sense of accomplishment.

Looking Ahead

Charles E. Bish, Director of the N.E.A. Project on the Academically Talented Student (10), predicts that by 1970 there will be available better instruments for measuring intelligence and related factors contributing to achievement, particularly creativity; that there will be better understanding of what can be done for the gifted; that there will be more flexible organizations for class scheduling; that there will be greater opportunity to develop more effective methods for coping with individual differences.

Many of the practices and programs that have been described here will, no doubt, be adopted and instituted on a broad scale throughout the nation.

It is possible that in the future capable high school students will be eligible for honors sections of college courses in biology, honors colloquia, and opportunities to engage in independent research in college. Continuity of the college program with the enrichment program in biology in the high schools is a desirable goal.

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III

Beginnings in Developing an Art of Investigation

Paul Brandwein*

CLEARLY, NOT ALL students will consider the life of the investigator as a life's work. They will, on appropriate occasion, use whatever art of investigation they possess. We are concerned here with the small, nevertheless important, group of individuals who will become investigators in biology—of whatever rank.

An investigator has his beginnings. It is wasteful to suggest that, since completely valid and reliable methods of identification of future investigators are not available, our identification must wait on the discovery of these methods. It is equally wasteful to accept the premise that our schools are not yet equipped to deal with truly creative individuals. Whether or not these premises are true, the students exist, and so do the schools, so do teachers, and so do various practices and techniques (see Ch II). We may assume that these practices and teaching techniques are personal inventions of different teachers who have achieved some success in stimulating students to undertake the investigator's work, whether in school or college.

Defined for our purposes, teaching technique consists of *all* the devices (knowledges, skills, attitudes) teachers develop to guide students to the fullest development of their aptitudes.

* Assistant to the President, Harcourt, Brace and World; Director of Education, The Conservation Foundation.

Since teaching technique is a personal invention it must often anticipate research—and if a curriculum is not available, it must be invented; and if a method is lacking, it must be fashioned out of bits of theory, bits of research, bits of practice, bits of imagination, and even bits of hope.

What is "success" in terms of developing students who are skilled in the art of investigation? The problem may be turned around so that it is operational: *What kind of school environment can we fashion that will give students the greatest opportunity to learn how to investigate?* In the absence of tests clearly designed to select the investigator, it seems just as clear that our present road is to prepare so rich a learning environment that the student-investigator will *elect* the opportunity to investigate. *Election* of opportunities, rather than *selection* of students is our bias; but not without carefully planned yet *non-coercive* identification of able students. The kind of identification we prefer occurs mainly through participation in imaginative learning, made possible by teachers who are scholars and vibrant people, as well as through formal guidance and careful testing.

General Assumptions Relating to the School Atmosphere

Four assumptions, based on observation of some 1,000 teachers in biology—over a period of 10 years—are permissable; necessarily the statements of the assumptions are over-simplified.

1. *We may assume that in those schools where the freedom to investigate is highly characteristic of curriculum and teaching method there exists a greater opportunity for students to learn the methods and the advantages of the investigator's life.*

How does an individual learn his craft? A painter paints, a writer writes, a musician plays his instrument, an investigator investigates—even as he searches the archives (texts, monographs, papers) that have led up to his time. The past is prologue. To learn to originate, to make the fertile leap into the dark, one must practice the "leap." One must learn to fail intelligently. One begins somewhere and goes somewhere. So it seems does an investigator.

In those schools which support our assumption above, there is a generous, not a parochial, view of the scientist's way of investigating. In those schools the scientific "method" is more generally recognized as individual "method," or as Beveridge puts it, as "an art of investigation." Bridgman's idea of the scientist's way as a "method of intelligence" or Bronowski's notion of the scientist's search for "hidden likenesses," or new relationships, if you will, also seems to be characteristic. The idea of *steps* in sequence in a processional scientific method is meretricious; insight into the hidden likeness may come in a "flash of insight."

2. *We may assume that opportunities for early identification of potential investigators will occur in those communities where the schools make opportunities for investigation early in the school career, that is, in the elementary school.*

It seems clear that without opportunities to investigate—in the elementary, junior, and senior high school years—able students who might otherwise do so may not choose investigation as a life's work. This seems almost axiomatic, yet even in this period of history one hears of college and university teachers and administrators who wonder (in public press or platform) whether science should be taught in the schools.

It also seems fairly evident that 10th year biology or 12th year physics may not be the time to develop investigators in biology or physics; potential investigators may have long since decided that science is not for them. It is almost obvious that poor science teaching in the elementary and junior high school grades may eliminate many future biologists or physicists. This is not to say that science has a priority; it is to say that science (as a way of life) ought to be given a fair chance. The same is true for art, music, literature, the behavioral sciences, the social sciences. The earlier students meet opportunities for investigation (synonym: individual search for knowledge) in all areas—the earlier students develop in a school environment that embodies the psychological safety and freedom characteristic of the investigator's approach—the earlier will a view of their special world and career come to them.

3. *We may assume that where there is a broad approach to the curriculum, the more adequate will be the environment for investigation.*

The full-bodied curriculum is characteristic of the schools with reputations for good teaching—and for producing an excellent student body.

We consider the curriculum as consisting of *all* the activities in which teachers and students take part in fulfillment of their purpose. So a "science club," and "individual" investigation at the school laboratory (or at home, or at a hospital, or at a private or university laboratory), a lecture by a visiting scientist, a trip to the Smithsonian, is *part* of the curriculum. The course of study per se is *not* considered as equivalent to the total curriculum—but, it is necessary to repeat, only a part of it. Furthermore, the course of study is not considered as the same for all students; different textbooks are used for different levels, and different laboratory work for different levels may be scheduled (see "Block Approach," p 33).

4. *We may assume that the more nearly the "pattern" of the school encourages and rewards individual responsibility for personal behavior and stimulates development of independent scholarship the greater will be the stimulation of individual investigation.*

The experienced observer senses the tone of a school almost the moment he enters it. This holds true when observing teaching in a classroom. Of course, this "intuition" may result from much practice in observation and experience in teaching. The science work in those schools that were successful in stimulating individual investigation seemed to have related patterns. The following traits suggested the essence of the pattern:

a) At least one teacher in the department was a scholar in the field; he maintained scholarship through advanced university courses, or work toward a degree, or research, or serious reading. He also had the energy and the desire to work with individual students. (The characteristics of such teachers have been described on p 19, French; Knapp and Goodrich; Brandwein.)
b) The guidance program tended to give emphasis to individual interviews and, where possible, to individual testing (after group tests have been given). Also, it was generally true that the home-room and science teachers would function as counsellors as well, in the specific area of the course of studies.
c) There was clear emphasis on intellectual attainment as the prime objective of the school; scholarship did not take second place to sports. But physical fitness was held as one of the prime goals for all.
d) The curriculum was up to date; experimentation with the "newer" curriculums was going on in at least one "experimental" class.
e) In the laboratory the leaning was toward individual rather than group work. Demonstrations by the teacher did not rob students of the right to discovery.
f) There was an emphasis on problem-solving in addition to the traditional problem-doing. (Operationally: *Problem-solving* implies that the solution to the problem is deferred over a relatively long period; it may not be in a readily available reference, or it may not yet be published. Problem-solving implies originality. In *problem-doing*, the solution is to be experienced within a reasonable, predicted period, say within a laboratory period or perhaps during the period assigned to homework.)
g) The teaching pattern, the curriculum, the kinds of instructional materials all tended to stress conceptual schemes and concepts—rather than memorization and recall-on-demand. Books were chosen for their tendency to organize content around major concepts. The texts that organized their content around an anthology of topics were not in favor.
h) The administration was sympathetic to science and to individual investigation; funds and space were made available without sacrifice of other parts of the program. At the same time, the administrators and supervisors tended not to be laissez-faire in their attitude towards the science program; they showed active interest and took an active part in planning.

In short, common agreement in the school whose "pattern" we have sketched seemed to suggest that the best gauge of sound development, in a democratic society, is perhaps this: what is the greatest amount of *freedom* that can be permitted students, consistent with the ideals of competence in scholarship, health in body and mind, maturity, and independence?

Given the kind of environment that fulfills the four assumptions supporting our observations, it is fairly easy for a teacher to develop a personal teaching invention that stimulates individual investigation. Without this environment, such an invention is more difficult to come by, but still, many teachers have come by it out of barren ground.

The Individual Student and His Investigation

The Problem of Selecting a Problem

In discussions with teachers concerning the techniques of developing the beginnings of an art of investigation in high school students, the inevitable first problem is this: how do students get problems that are within their range and the range of the school situation? There are no hard and fast answers, but there are some suggestions based on observation of teachers who seemed skillful in stimulating individual investigation.

Clearly, it would be fine if all students came to the teacher with problems they had clarified for themselves—and within the range (funds, equipment, safety regulations) of a high school. This happens often enough but many times the student needs help in developing problems within the range we have discussed. For instance, a problem concerning physiologic races of corn or oat smut is probably not within the range of most city schools, while a problem involving the uses of a hospital laboratory, or a computer, or an electron microscope, is probably not within the realm of a rural school. Also it is possible that students may choose problems involving *considerable expense* (for example, involving equipment for maintenance of sterile tissue cultures), *danger* (highly pathogenic organisms), or *unnecessary difficulties* (maintenance of organisms that require excessive care, such as monkeys). A very useful check then on the feasibility of doing the problem in a high school laboratory are these:

a) With the statement of the problem, the student is required to give a budget of funds, or sources of equipment. If the budget is excessive, a limitation is either put on the problem or the problem is declared not feasible for the high school laboratory.
b) To clarify the problem, a design of an experiment is required. The experimental design indicates whether the student understands the problem.
c) With the statement of the problem a plan of reading is required as well. The nature of the reading indicates whether the level of the investigation transects the student's level of ability.
d) With the problem, it is useful to have an estimate of the time required to do the investigation.

An estimate of the time affords a clue whether the problem is realistic, whether the budget is warranted, and whether the investigation is within the student's ability range. All of these give an index of the practicability of working on the problem.

Assume that judgment precludes engagement in the problem. Should the student be discouraged? Perhaps. Some teachers who have acquired skill in teaching the art of investigation have also been able to secure aid in determining whether the problem submitted can be investigated. In a word, they have secured the aid of college and university professors or industrial scientists.

Aside from the kind of review indicated in the four points above, college, university, or industrial scientists in the community may suggest problems—and often make loans or gifts of equipment, or make available space in a laboratory.

To teach the art of investigation, it is not necessary to have intricate equipment. It is necessary only to find a problem that probes the student's ability and energy. What are some sources of such problems? The following suggestions are given without placement in order of significance.

1. *The student's own interest.* In our experience, this is a most fertile source. Once a student's keen interest is stimulated, he will keep reading, and thinking, until a problem occurs.

Sometimes, however, the student expresses interest in a field and asks for a "project." If his interest is clearly related to a field (ecology, genetics, physiology), then reading in the field, particularly a college text, may suggest a problem. (A comprehensive bibliography is given in Chapter 4.

2. *The teacher's interest.* The teacher's interest may lie along two avenues: the first may be in certain areas of biology, the second in a special field in which he or she might have done some investigations.

During the course of his teaching, the teacher may have many opportunities to point to unsolved problems within the range of his students. So in the laboratory, he might ask, "I wonder if it wouldn't be interesting to find out how long a *Blepharisma* digests another protozoan (in its food vacuole)?" Or, "Do trees growing alongside street lights bud earlier or flower earlier than others?" (These questions are not apocryphal, nor are the situations; they led several students to investigations.)

On the other hand, the teacher may have a special interest in a special small field of research in ecology, or protozoology, or genetics—the range of interests of teachers in the United States encompasses the field of biology. It is entirely practicable, in our observation, to start students on projects or specific problems in the teacher's field of interest. Why not? High school students, being what they are, will often use the project suggested as an introduction to the field. The most imaginative and independent students soon modify the original problem. For instance, a problem on the range of germination of oat smut *(Ustilago avenae)* spores led to a mathematical study that aimed at predicting hyphal size, under different conditions of germination, of the smut spores on host species of *Panicum*.

3. *The range of the school and the community.* A school

near a hospital or near a research laboratory, near an aviation plant, near a pond or oceanside may lean toward problems related to the material at hand. Conceivably schools near Eastman-Kodak at Rochester, New York, may take on problems related to photography or microorganisms; schools near Bethesda, Maryland, may lean to problems concerning health; in an agricultural area, problems in plant and animal growth may receive emphasis. Similarly, near a university, or an industrial plant, students may turn to experts in specified fields. Near Cape Canaveral, Florida, we may imagine certain interests not available in Providence, Rhode Island. As a further example, a school near a university in which genetics is a "strong" field may "originate" problems dealing with mutation in *Neurospora;* a school near a pharmaceutical research laboratory may "originate" problems dealing with the effect of tranquilizers on mice.

Surely the teacher and student should use the community and the environment as a source of problems worth investigation. This is one of the objectives of sound education.

4. *The university sponsor.* Recently college and university biologists have shown considerable interest in the development of biology courses for students in the high school. The Biological Sciences Curriculum Study is one such result.

With this interest is a concomitant one: there is a willingness amongst many college, university, and industrial scientists to assist students in developing experimental designs and in gathering equipment. It may well be that one attribute of a resourceful science teacher is to cultivate available university resources. If this is done with decent regard for the particular human relationships, the requests for help will not become oppressive.

Most useful, of course, are the resources of the university, particularly its library. Qualified students, acting under an established relationship between the high school and college biology departments, may acquire reading privileges. A rich source of suggestions for problems is *Biological Abstracts,* where summaries of research may suggest a variety of problems.

Sometimes a biologist may sponsor youngsters in research. Such sponsorship is becoming more common as the Summer Institutes for High School Students (sponsored by the National Science Foundation) bear fruit. An outcome of the Joe Berg Foundation Seminars (App G) provides a similar kind of sponsorship.

5. *The sources of problems inherent in the Biological Sciences Curriculum Study.* Anyone who reads the courses being developed by the Biological Sciences Curriculum Study, who studies its Block Laboratory Programs, who reads its Bulletins and Newsletters will find sources for problems.

Reference may be made once again to two of the volumes of material made available through BSCS: *High School Biology, Biological Investigations for Secondary School Students.* There has not been sufficient time to evaluate the uses to which these volumes have been put, but there is increasing indication that they are useful in suggesting problems.

6. In the end, and perhaps this has been said ad nauseam, *the individual teacher invents his own means for teaching the art of investigation.* There have been many reports of useful practices, particularly those noted in the accompanying papers in this volume. In the appendix are listed titles of some student projects and also some titles of papers written by biology teachers describing their own teaching inventions (STAR). The publications of the Superior and Talented Student Project describe further class activities of individual teachers or schools (see App C, D, E, G, H).

In the opinion of many high school teachers who have developed techniques for teaching an art of investigation, the most crucial limiting factor is not the difficulty of securing problems but the routine of managing the research.

Routines in Management

Whether a teacher has time to work with individual students depends to a surprising extent on his practices in class management, as well as on his scholarship. It depends to a considerable extent on the support of the administrative officers in the school. For instance, one teacher agreed with the necessity of developing opportunities for individual investigation, but found his class time interrupted by calls upon him to secure equipment, to check on the whereabouts of students, to supervise the laboratory, and to do a myriad of things that were not expressly directed toward the apparent task of teaching the art of investigation.

Three elements of routine need solution almost before the teacher can embark on work with individual students: i) the allocation of appropriate working space and suitable schedules; ii) the ordering, care, and preparation of equipment; and iii) the reporting of work done.

1. *Where can students do individual investigation?* Let the principle be established that wherever there is room for one student to work alone, there is room for the carrying on of individual investigation. It would be fine if investigation could be carried on in a *properly* equipped laboratory; but individual investigations can be done at home, certainly in a university, hospital, or industrial laboratory. One of the most ingenious investigations the writer observed was done in a corner of a classroom where no water or gas was available. A carboy with siphon served as a sink, a bucket for waste, a wash bottle for rinsing, a small propane burner for gas, and a card table covered with an asbestos sheet as the laboratory table.

Furthermore, wherever individual investigation is done, it is clear that the teacher, or sponsor, cannot and indeed should not—in the name of independent scholarship—stand over the investigator's shoulder. Unless the work is dangerous for the beginning investigator, there is no need for the student to work in the vicinity of the sponsor. (If it is dangerous, should it be done in a high school?)

Indeed the work of Lewin, Lippitt, and White (2) confirms the need for regulations that are neither inflexible nor laissez-faire. Note also a similar report by Brandwein (1) (who describes suitable "working conditions" for young investigators working in groups). The essence of supervision of the young investigator seems to be that the sponsor be available for guidance, that he "visit" the laboratory to ask whether he can be of help, that he ask the "right" questions and suggest further readings—but not tell the student the "right" way to do things. Neither is it desirable to spare the young investigator error, if the student has confidence in his experimental design.

Certain precautions, however, are useful:

a) The student should agree to comply with simple regulations. For instance, the teacher must know where he is during school hours: in the library, laboratory, or study hall, for example. This is especially necessary where live animals are under study. Other regulations refer to the opening and closing of the laboratory (gas off, etc.); the adherence to safety precautions (use of dangerous substances such as concentrated sulfuric or nitric acids, ether, etc.); the care and feeding of animals. It is well to develop a list of safety precautions fully annotated as to the necessity for their adherence. (One such list is appended; see App B.)

b) It is well to have students sign a duplicate copy of the safety precautions; this stresses the importance of adhering to them.

c) It is well for the student to sign in and out of the laboratory (with a notation of time) whenever he does his investigation. The teacher may then estimate whether appropriate time is being given the investigation or whether the student is spending more time than is consistent with his total school program.

d) It is useful for the sponsor to schedule regular conferences with individual students, perhaps once a week.

2. *Securing equipment.* Sometimes the equipment desired is impossible to build or secure. Then the problem may well be out of the range of the school. But if the investigation is to be

carried out over a period of a year or two, it is highly desirable for the young investigator to build some of the equipment.

It is highly undesirable for the student to interrupt the teacher in his duties to seek equipment on the "spur of the moment." In our experience, it was well to organize the work so that equipment could be secured on 1 or 2 days of the week, and *only on those days during specified hours.* If the equipment had not been ordered on those days, the student could not then proceed with the work. If nothing else, the student soon learned to plan his work. There is need to emphasize the importance of situations that encourage planning. Other precautions worth noting are these:

a) It is well to have the student's parents acquainted with the nature of the student's investigation. This allows a special avenue of communication to be established between the student's sponsor and the parents; guidance is made more effective.
b) It would be necessary to train the student in the use of new or unfamiliar equipment and techniques, such as, sterilizer, binocular microscope, dissecting equipment, handling of animals, etc.
c) It is very helpful to organize a laboratory squad to staff the storeroom, make equipment and materials available, keep the equipment in repair and the general laboratories in order. The organization and training of such a laboratory squad is described in *A Sourcebook for Biological Sciences* (3).
d) If funds for equipment are not readily available, it may be desirable to develop an advisory committee recruited from industry. Such a committee may be of great service in securing funds and equipment.

3. *Reporting on the progress of the investigation.* It is useful to help the student appraise his own progress. For this purpose, regular recording of observations and reporting of the progress of the work is helpful. Several procedures are worth noting:

a) The student should keep a notebook in which his daily work and observations, carefully dated (date and time), are recorded—in his own style. This notebook should be kept at the place of work.
b) A monthly report (one page or so) to the teacher, of progress of the work, might also be useful. In this report, a note about reading done (with careful notation of bibliography) should be included.

c) A "seminar" might be held, or oral report might be made, once every 2 months. If all student investigators could be present, valuable interchange might well result.

d) It is useful to have students make a complete semiannual report in writing. If it is possible, or desirable, an exhibit of the work should be constructed.

e) Once a year, an assembly program might be held at which students reported their work.

f) Whether or not the investigator should enter his work in a Science Fair, or National Science Talent Search, remains within the scope of the school's policy. From the viewpoint of psychological safety and freedom, it is not necessary to require that the work be exhibited at a Fair, or entered in the National Science Talent Search, or suggest that it is desirable to do either. Rather, independent scholarship, quietly and modestly pursued, might well be the objective. But there is no reason why appropriate and suitable rewards might not be available. For instance, a very useful and desirable reward given by one teacher was to include the student's own paper—where it was considered worthy—with the student's application for college entrance. In another instance, in a large school, a journal was developed in which research papers were published.

Without being mawkish about it, science still remains an area where the ideals of the truly civilized have a chance to exist. The uniting of a student's gifts—with opportunities for their fulfillment—still remains the objective of the school. Publicity may at times not be of help. What is of the essence is pressing forward with the work at hand. Clearly one seeks any helpful device, invention, or procedure that maintains the integrity of the student, of the teacher, of the school, and of science.

4. *By way of example.* Let us assume that a student becomes deeply interested in a prospectus such as the one below submitted by Dr. Walter Rosen: "Investigations of Pollen Tube Chemotropism."[1] Some students might begin this problem by reading more deeply in a college text (see Ch IV) on the topic of plant reproduction, growth, and hormone effect. Another

[1] Dr. Rosen is a member of the Gifted Student Committee. See also, *Biological Investigations for High School Students,* Vol. I.

dent could well begin by investigating the growth of pollen grains by germinating them in class; in this way he might determine whether the problem had interest for him. Still another would perhaps ask for references on techniques. For another the prospectus would merely serve as an introduction to the problems related to germination of pollen grains, or even spores; perhaps this would result in his seeking original papers in journals. In all these cases, a design for an experiment ought to be submitted, accompanied by a request for equipment.

Perhaps most students would take Dr. Rosen's suggestions for problems, as stated in the prospectus (see below), and proceed from there. There may be as many approaches to the problems as there are students.

There are 150 of these prospectuses available in the companion volumes, *Biological Investigations for High School Students* (BSCS). They all have the format presented in Dr. Rosen's paper, which is presented below as an example of a prospectus offering fruitful suggestions for investigation by capable high school students. Note its form, which is suggestive of the 150 prospectuses offered: Background, Some Problems to Investigate, Suggested Approach, Pitfalls and Special Problems, and Suggested Readings. All in all, the prospectus embodying these clues furnishes a good start for an investigation.

Investigation of Pollen Tube Chemotropism

Walter G. Rosen

Dept. Biology, Marquette University

Background:

The union of gametes is an essential event in the life history of most organisms, and it is therefore surprising to note that neither the chemicals responsible for gametic attraction, nor the mechanim of their action, have been much studied.

For many organisms it has long been known that union of sperm and egg results not merely from random collisions. Thus, the male gametes of ferns and mosses were observed over 70 years ago to be attracted to the archegonia in which the eggs are located, and Pfeffer discovered that these motile sperm were also attracted to capillary tubes containing malic acid. The motile male gametes of many fungi are similarly attracted to the egg cells, and, recently, progress has been made in describing the chemical produced by the female cells which is responsible for this attraction.

This phenomenon of attraction of motile cells by chemicals (CHEMOTAXIS) is not limited to plants, nor to sex cells. There is evidence for chemotaxis in vegetatae cells of cellular slime molds, and in leucocytes, as well as in sperms of higher animals. And the phenomenon is not limited to motile cells. Non-motile cells may *grow* toward or away from chemical stimuli (CHEMOTROPISM). Thus, fungal hyphae are attracted by mixtures of amino acids, and pollen tubes are attracted by parts of the pistils in many flowering plants.

Of the various cases of chemotropism and chemotaxis which have been reported, chemotropism of pollen tubes to pistil tissues is probably most readily demonstrated and easily studied. Suitable experimental material is available, culture medium is quite simple, and pollen tube growth is rapid.

Some Problems to Investigate:

Can chemotropism be observed in all species of plants? Is it limited to certain genera, families?

Can the pistils of one species attract the pollen of other species of the same genus? Of the same family? Of other families?

Are pollen tubes attracted to the same substances that have been reported to attract other cells (e.g.: amino acids, malic acid, aggregation centers of cellular slime molds, or steroid sex hormones)?

Is the chemotropic substance of pistils resistant to heat? Will the chemotropic influence be exerted if a differentially permeable membrane is inserted between pistil and pollen?

Is there a correlation between the presence (or absence) of chemotropic attraction and the ability of various pistil-pollen combinations to produce fertile seed?

Are pollen tubes equally attracted to all parts of the pistil? Are they attracted to non-reproductive portions of the plant?

Is there a peak time of chemotropic activity during development of the flower? Does chemotropic attraction disappear after pollination?

Can the active material be extracted from pistils, purified, and identified?

Answers to any of these questions will contribute significantly to our knowledge of the physiology of reproduction.

Suggested Approach:

Pollen of many species will germinate readily on a synthetic medium consisting of 5–15 percent sucrose, and 1 percent agar. Boron (as boric acid, about 10 ppm), yeast extract (about 100 ppm), and Gibberellic acid (about 50 ppm) may be added to the medium if percentage of germination is low or if growth of the pollen tubes is poor. If the medium is freshly prepared for each experiment it need not be sterilized. Most pollen will germinate and show a chemotropic response in 2–6 hours, and since little bacterial growth occurs in this short time, sterile procedures are not necessary.

One way of investigating chemotropism is to place pieces of freshly excised pistil on the surface of the hardened medium in Petri dishes; arrange pollen grains around the pistil tissues with the aid of a fine camel hair brush. Pollen should be placed close to the tissue (within a few mm) for chemotropic response to be observed. It is necessary to arrange the pollen, and to observe the growth of the pollen tubes, with the aid of a binocular dissecting microscope (approx. 5–10 X magnification).

Liquids may be tested for chemotropic activity by placing them in wells formed in the agar medium with the aid of a cork borer, and then placing the pollen around the rims of the wells.

Pitfalls and Special Problems:

It is likely that pollen of different plants will have different requirements for germination and growth. Thus it may be necessary to vary the composition of the medium. The medium described here provides for good growth of the pollen of various species and hybrids of Lily. It will be necessary to devise a method for scoring the amount of chemotropic attraction which you observe, perhaps by counting the number of pollen tubes growing toward, and away from, the test substance. Controls might consist of pollen arranged around test wells containing distilled water, or around inactivated pistils.

Suggested Readings:

General

1. Sinnott, E. W., and K. S. Wilson, *Botany: Principles and Problems* (Chapter 13, Reproduction), McGraw-Hill, New York, 1955.

Specific

2. Brink, R. A., "The physiology of pollen," *American Journal of Botany,* 11:218, 283, 351, 417, 1924.

3. Machlis, L., "Evidence for a Sexual Hormone in *Allomyces*," *Physiologia Plantarum,* 11:181, 1958.
4. Rosen, W. G., "Studies on Pollen Tube Chemotropism," *American Journal of Botany,* 48, Nov.-Dec., 1961.
5. Rothschild, L., *Fertilization,* Methuen, London, 1956.
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2. Lewin, N., R. Lippitt, and R. White. 1939. "Patterns of Aggressive Behavior in Experimentally Created Social Climates," *Journal of Social Psychology,* 10, 271–279. Also see White, R. and R. Lippitt. 1960. *Autocracy and Democracy: An Experimental Study,* Harper.
3. Morholt, E., P. Brandwein, and A. Joseph. 1958. *Teaching High School Science: A Sourcebook for the Biological Sciences,* Harcourt, Brace.

IV

The Student Investigator and the Library

Walter G. Rosen*

THE STUDENT investigator needs an introduction to the literature in his field of investigation. His teacher can help him make a start at it by directing him to sources of information.

Ideally, the student would have at his disposal a good basic high school science library, one containing, perhaps, the books included in the AAAS Traveling Science Library, as well as subscriptions to *Science, Scientific American,* and *the American Scientist,* perhaps a few other general science periodicals, and a good encyclopedia. Ideally, too, there would be available to students a good public library and/or university library. This is not a common situation; we can get along with a good deal less, for a "minimal" library cannot be defined for all projects. To some extent, the wisdom of encouraging a student to engage in a particular study will be tempered by the facilities, both library and laboratory, that are within reach.

There are two things that the student can accomplish with the help of the scientific literature. The first is to achieve literacy in the area of his interest. Literacy in a biological area can be thought of as having two dimensions. One of these we shall call the dimension of "approach." By this we mean the type of study to be undertaken, regardless of the specific organism under investigation. The types of approach might be: physiological, ecological, morphological, behavioral. Literacy in the physiological type of approach involves command of the

*Department of Biology, Marquette University, Milwaukee, Wisconsin.

basic concepts of physiology, plant or animal or possibly both. The other dimension of literacy can be termed the "organismal." Thus, if one were interested in the bean plant, it would be necessary to understand its classification, physiology, morphology, and so forth, in order to be competent to study it by any approach.

Here the teacher can help the student decide at what level to begin the development of general literacy. Depending on the student and on the problem he has selected, background reading may well begin with a freshman college textbook of botany, biology, or zoology, to be followed by more advanced books in specifically defined fields: plant pathology, animal behavior, experimental cytology. One contribution of the teacher, then, is to help the capable student to grow in general literacy in both dimensions: bean and physiology, ant and ecology, or whatever the investigation may be. We have compiled lists of journals and texts that we have found useful in working with students (p. 64).

In the BSCS publications, *Biological Investigations for Secondary School Students* (1961–62), are research problems which have been submitted by scientists. Accompanying each paper is a bibliography listing background readings. The lists are not exhaustive; they are guides to the literature; other books might well be substituted.

Concurrently, the student investigator will need to become acquainted with the specific, original scientific literature which relates directly to his selected problem. Have the effects of *this* plant hormone been studied on *this* species? On closely related species? Have the effects of other hormones been studied using this or a related species? Where can he find the answers? His gain in general literacy in an area will likely provide the guide for locating original scientific literature relevant to his project. For example, many textbooks contain references to the original research papers from which the textual material was derived. General and popular articles, such as those published in *Scientific American*, the *American Scientist*, *Endeavour*, and *Encyclopaedia Britannica*, also contain references to pertinent reviews and to original research.

Once the student has progressed through literature references, from a general article or a text chapter to the research publications, he will be well on his own in searching the literature; research papers generally list and discuss other research papers.

However, new research papers are being published all the time; the student will need to learn other sources for reference. Book reviews are offered by many science journals; abstract journals and reviews provide a more systematic means of tracking down older published research findings and of keeping abreast of new publications not yet found in texts. Perhaps the most useful of the abstract journals is *Biological Abstracts*. Each monthly issue lists brief summaries of thousands of research papers published in journals throughout the world. Abstracts are arranged according to subject so that a student can turn directly to the topic "photosynthesis," rather than check all of the entries in the issue. The subject indices of *Biological Abstracts* permit rapid scanning of the published literature of many years, while the current issues provide a way to keep apace of what is being published. The availability of reprints from authors provides a means for those students located in areas with limited library facilities to gain access to the needed papers. It must be stressed that investigators have a limited number of reprints and students should not take undue advantage. A subscription to *Biological Abstracts* (or to specific portions of it, like the "Plant Science" abstracts) would be a valuable addition to the high school library.

Other important review periodicals are *Botanical Reviews*, *Zoological Reviews*, *Quarterly Review of Biology*, *Physiological Reviews*, *Bacteriological Reviews*, and many more. In addition, there is another series, published by Annual Reviews Incorporated, Palo Alto, California. These reviews include, in separate series, annual reviews of papers in biochemistry, microbiology, plant physiology, agronomy, to list only a few. Each issue in each series contains a variety of articles; a recent issue of the *Annual Review of Entomology,* for example, contains among others, papers on insect pigments, microbial control of insect pests, taxonomic problems with closely related species.

The annual publications of the United States Department of Agriculture, the Yearbooks, are an excellent source of general articles of current work with a bibliography of original papers. Some of the past titles have dealt with Insects, Seeds, Food, Soil, and Trees.

Inspiration, valuable research leads, new relationships, may be found in the most unlikely places. The student should therefore be encouraged to read widely in the literature, for here, as often as in the field or laboratory, chance favors the prepared mind.

A Guide to the Literature of Biology*

COMPREHENSIVE AND GENERAL READING

Periodicals

American Journal of Botany
American Scientist
Biological Abstracts
Biological Bulletin
Biological Reviews
Botanical Reviews
Brookhaven Symposia in Biology
Cold Spring Harbor Symposia in Quantitative Biology
Endeavour
Proceedings of the National Academy of Science
Quarterly Review of Biology
Scientific American
Zoological Reviews

* Grateful acknowledgement is made for the contributions of the members of the Committee to the preparation of this Bibliography.

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Special Techniques: Culture Methods

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SPECIAL FIELDS

Animals: Anatomy, Physiology

Periodicals

Endocrinology
Entomological News
Entomological Review
Journal of Cellular and Comparative Physiology
Journal of Experimental Zoology
Journal of General Physiology
Journal of Insect Physiology
Journal of Mammology
Journal of Marine Research
Journal of Molecular Biology
Physiological Reviews
Physiological Zoology

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Biochemical Journal
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Cell Biology and Microtechnique

Periodicals

Cytologia
Experimental Cell Research
International Review of Cytology
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Journal of Embryology and Experimental Morphology
Symposia; Society for the Study of Development and Growth

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Journal of Animal Ecology
Journal of Ecology
Journal of Experimental Psychology

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Journal of Genetics
Journal of Mammology

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Advances in Virus Research
Annual Reviews of Microbiology
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Contains papers by Ross Mooney and Carl Rogers (amongst others) on the nature of creativity. Report includes conference reports and suggested research studies.

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Highly readable descriptions of designs for experiments with several examples. Chapter 7 deals with the "Thinking of the Experimental Scientist," and Chapter 8 is "First Hand About Experimental Thinking."

Bendig, A. and P. Hountras. 1958. "College Student Stereotypes of the Personality Traits of Research Scientists." *Journal of Educ. Psych.,* 49:6.
Retention of same stereotypes: research scientists are more intellectual, logical, orderly, persistent, etc., less charming, less friendly, less poised, etc.

*Prepared by Paul Brandwein, Assistant to the President, Harcourt Brace and World, and Director of Education, The Conservation Foundation; and Evelyn Morholt, Chairman of Biology and General Science, Fort Hamilton High School (N.Y.)

Bentley John. 1937. *Superior Children.* New York: W. N. Norton and Company.

An early work which discusses the nature of intelligence and of talent among these students. Includes useful methods of instruction.

Bevan W. 1961. Perceptual Learning: An Overview. *Jr. General Psych.*, 64, 69–99.

Review of perceptual frame of reference that has cogent appeal for readers interested in problems of thinking and creativity.

Beveridge, W. I. B. 1957. *The Art of Scientific Investigation.* W. W. Norton.

An invigorating study of scientists and their methods. There are chapters on experimentation, chance, hypothesis, intuition, imagination, strategy, reason; also attributes required for research and the scientific life.

Bigelow, G. E. 1959. "Who Should Teach the Superior Student?" *Journal of Teacher Educ.*, 10:130–131, June.

A plea for selecting a superior teacher for gifted children; even a stronger plea for setting him free to teach his own way.

Bish, Charles. 1959. "Teaching the Upper 15 Per Cent." *Clearing House,* 33:515–518, May.

Ten "liabilities" and 12 "objectives" for teaching these youngsters at all grade levels.

Blanchard, W. 1958. "Intellectual Inhibition and the Search for Scientific Truth." *Jr. Soc. Psych.*, 47.

A discussion of circumstances affecting fulfillment of human talent. Descriptions of some studies on intellectual inhibition have a bearing on problems affecting "giftedness" in science.

Bloom, S. W. 1955. "The Early Identification of Potential Scientists." *School Science and Mathematics,* 55:287–295, April.

Details of how four high schools select students for special classes; the general characteristics of such students.

Bloom, S. W. 1953. "Science Provisions for the Rapid Learner—A Symposium." *The Science Teacher,* 20:161–163, September; 243–246, October; 291–297, November.

A general view of methods of identification. Also reports by eight workers in the field on provisions for rapid learners from elementary through high school.

Bond, H. M. 1959. *Search for Talent.* Cambridge, Massachusetts: Harvard University Press.
A plea to find (at the high school level) all the talent in the human resources of our nation, in rural regions, in underprivileged areas—especially amongst all races and creeds of the nation.

Brandwein, Paul F. 1955. *The Gifted Student as Future Scientist.* New York: Harcourt, Brace.
A report on a program in one high school; from an observation of the specially talented students in the program, methods of identification and instruction are derived. Also a conceptual scheme on the nature of giftedness.

Brandwein, Paul F. 1947. "The Selection and Training of Future Scientists." *Scientific Monthly,* 64:247–252.
An early paper analyzing the nature of the problem of selection and training of the scientist-to-be.

Brandwein, Paul F., et al. 1960. "Creativity and Personality in the Scientist." In *Rethinking Science Education,* 1959 Yearbook, Part I, National Society for Study of Education, University of Chicago Press, 63–81.
Paper describes some aspects of social atmosphere, and of personality which seem to be factors in the choice of a scientific career. Also presents a picture of an individual "successful in science."

Brandwein, Paul F., F. Watson, and P. Blackwood. 1958. *Teaching High School Science: A Book of Methods.* Harcourt, Brace and Company.
Special chapter on the "science-prone"; methods of selection and instruction.

Bray, Douglas. 1954. *Issues in the Study of Talent.* New York: King's Crown Press, Columbia University.
Discussion of various theories of intelligence and talent. Bray feels individual's ability is interaction of innate learning potential, quality of the learning experience, and emotional drives.

Brumbaugh, F. N. and B. Roshco. 1959. *Your Gifted Child.* New York: Holt.
The book is written mainly for parents of such children. It contains sections on understanding giftedness, and working with gifted children.

Bruner, J., J. Goodnow, and G. Austin. 1956. *A Study of Thinking.* Wiley.
Thorough discussion of some tactics and strategies in concept attainment.

Bulletin of the National Association of Secondary-School Principals. 1953. "Science In Secondary Schools Today." Washington, D. C., 37:191, January.

Entire bulletin is devoted to science in secondary schools; includes several articles of interest for teaching gifted science students.

Bulletin of the National Association of Secondary-School Principals. 1955. "Education of Handicapped and Gifted Pupils in Secondary-School." Washington, D. C., 39:207, January.
Various articles throughout the journal will be of interest.

Burnett, A. Will. 1957. *Teaching Science in the Secondary Schools.* New York: Rinehart.
Specific suggestions for teaching gifted students in science are included.

Carmichael, L. (ed). 1954. "Gifted Children." Chap. 16, *Manual of Child Psychology,* Wiley.
Comprehensive review of literature on nature of giftedness, means of selection, and suggestions for teaching these children.

Carroll, Herbert. 1940. *Genius in the Making.* McGraw-Hill.
Presents a picture of the intellectually gifted mainly in the earlier years and interprets "mental superiority."

Cattell, R. and J. Drevdahl. 1955. "A Comparison of the Personality Profile (16 PF) of Eminent Researchers With That of Eminent Teachers and Administrators, and of the General Population." *Brit. Jr. Psych.,* 46, 248, 261.
Comprehensive study based on an analysis of sixteen personality factors.

Cole, Charles C. 1956. *Encouraging Scientific Talent.* New York: College Entrance Examination Board.
Ways of stimulating students to enter college and science; an analysis of the reasons why able students do not go to college.

Conant, James B. 1959. *The American High School Today.* New York: McGraw-Hill.
Includes an evaluation of and 21 recommendations for improving our high schools; recommendations 9 and 10 refer to the academically talented and highly gifted and recommendation 19 refers to science courses.

Conant, James B. 1948. *Education in a Divided World.* Cambridge, Mass.: Harvard University Press.
Presents three criteria for determining effectiveness of high school for gifted children and urges better identification as well as instructional practices. Importance of these youths to the nation is stressed.

Connecticut State Department of Education. 1956. *Education for Gifted Children and Youth.* The Department.
Pamphlet is effort of eight northeastern states. Discusses acceleration, special classes, identification, at various grades of the public school.

Cooley, W. W. 1958. "Attributes of Potential Scientists." *Harvard Educational Review,* 28, 1–18, Winter.
An analytical study.

Cruickshank, William (ed). 1955. *Psychology of Exceptional Children and Youth.* Englewood Cliffs, New Jersey: Prentice-Hall.
Contains material of interest to teachers of gifted youngsters.

Cutts, N. and N. Moseley. 1953. *Bright Children: A Guide for Parents.* New York: G. P. Putnam's Sons.
Aimed at helping parents guide children with an IQ range of 120 or above from elementary school to college.

Cutts, N. and N. Moseley. 1957. *Teaching the Bright and Gifted.* Englewood Cliffs, New Jersey: Prentice-Hall.
Discusses numerous aspects of teaching these students at both the elementary and secondary level. Material from scattered source is assembled in the text.

DeHaan, R. and R. Havighurst. 1961. *Educating Gifted Children,* 2nd ed., Chicago: University of Chicago Press.
Gives general background material concerning the gifted as well as suggestions for developing programs for them in elementary and secondary schools. This revised edition includes much of the expanded research on creativity and programs for the gifted.

d'Heurle, A., J. Mellinger, and E. Haggard. 1959. "Personality, Intellectual and Achievement Patterns in Gifted Children." *Psychological Monograph.* 73, No. 483.
Report of one phase of a 7-year research project in the Laboratory School of the University of Chicago. Since 1950, the progress of 76 children has been studied from grade 3 through 9.

Department of Health, Education, and Welfare. 1952. *Education for the Talented in Mathematics and Science.* Washington: U. S. Bulletin, No. 15.
Report of conference on methods of identifying and providing for talented students in high school.

Drevdahl, J. E. 1955. "Factors of Importance for Creativity." *Journal of Clinical Psychology,* 12, 21–26.
Relationships between intellectual and personality traits and ratings of creativity in a group of graduate students in science and arts departments of University of Nebraska.

Duncan, Carl. 1959. "Recent Research on Human Problem Solving." *Psych. Bulletin,* 56.

Summary of studies on processes and theories of problem solving from 1946–1957. Excellent bibliography associated with studies of creativity.

Dyer, Henry. *College Board Scores* No. 1 New York, College Entrance Examination Board.
Chapter IX includes a study of special norms on science tests made by "science oriented" and "undifferentiated groups."

Educational Policies Commission. 1950. *Education of the Gifted.* Washington: National Education Association.
The booklet discusses the identification and education of the gifted, the role of the gifted in a democracy, and our present waste of talent.

Educational Leadership 1956. "Curriculum and the Gifted," 13, January.
Theme of the issue is the education of gifted children.

Edwards, T. B. and A. Wilson. 1958. "Attitudes Toward Study of School Subjects." *Educational Theory* 8:4, 275–283.
Paper attempts to clarify "motivation" of high school students; raises problems related to creativity.

Endicott, Frank. 1961. *Guiding Superior and Talented High School Students.* Superior and Talented Student Project North Central Assoc. Colleges and Secondary Schools.
This book is directed mainly at schools that wish to improve their guidance services for identifying and counseling superior and talented students. There are practical chapters on motivating capable students; relationship of counselor with teachers, parents and community; also recommendations for evaluative criteria.

Everett, Samuel (ed). 1961. *Programs for the Gifted.* 15th Yearbook, John Dewey Society. Harper.
Describes methods of identification of gifted, and methods of teaching these children; a casebook in secondary school education.

Fehr, Howard. 1953. "General Ways to Identify Students With Scientific and Mathematical Potential." *Mathematics Teacher,* 46, 230–234, April.
Describes ten traits and suggests methods for identifying able students in the classroom.

Fliegler, L. (ed). 1961. *Curriculum Planning for the Gifted.* Prentice-Hall.
Offers suggestions for the total curriculum for the gifted. Specialists have written chapters on the arithmetic program, social studies, and science for the elementary and the secondary school levels.

Fliegler, L. 1959. "Levels of Creativity." *Educational Theory* 9.
Uses pyramid formation to describe lowest to highest developmental levels of creativity.

Fliegler, L. and C. Bish. 1959. "The Gifted and Talented." *Rev. Educ. Res.*, 29:5.
This paper reviews the literature over the past 6 years (since Newland's "The Gifted" in the *Review of Educational Research* 23, 1953)

Freehill, Maurice. 1961. *Gifted Children.* New York: Macmillan.
Compilation of methods of testing and administrative measures used in providing a rich curriculum; also a discussion of the psychology of highly capable students.

French, J. L. (ed). 1959. *Educating the Gifted.* New York: Holt.
A book of readings on identification, general provisions, specific programs, acceleration, underachievement, the teacher of the gifted, evaluation and research at all grade levels.

Fund for the Advancement of Education. 1953. "Bridging the Gap Between School and College." New York: The Fund.
Discusses nature and progress of four projects directed at improving articulation between high school and college as such articulation affects the gifted student.

Garrison, Karl and D. G. Force. 1959. *Psychology of Exceptional Children.* New York: Ronald Press.
One section is devoted to a study of gifted children at various age levels; the psychology of special abilities is described in another section.

Getzels, J. and P. Jackson. 1958. "The Meaning of Giftedness: An Examination of an Expanding Concept." *Phi Delta Kappan,* 40, 75–77.
Among other findings of their study, they noted that teachers gave higher ratings to high IQ group, whereas ratings to highly creative group were similar to those for student groups in general.

Getzels, J. and P. Jackson. 1962. *Creativity and Intelligence: Explorations with Gifted Students.* New York: John Wiley & Sons, Inc.
The major portion of the book is devoted to a detailed comparison of children who are high in creativity but not concomitantly as high in IQ with children who are high in IQ but not concomitantly as high in creativity. This comparison indicates that creative ability and high IQ are by no means one and the same.

Ghiselin, B. 1952. *The Creative Process.* Berkeley and Los Angeles: University of California.

An anthology of articles on the creative process by illustrious people from many fields in different times. The introduction is especially interesting.

Goldberg, M. L. 1958. "Recent Research on the Talented." *Teachers College Record,* 60, 150–163, December. (*Educ. Digest,* 24, 21–24, March, 1959.)

Survey of 41 research studies in this area.

Goldstein, Philip. 1957. *How To Do An Experiment.* New York: Harcourt, Brace.

Describes an approach to experimentation for secondary school students. Practical and useful.

Gordon, Garford, G. 1955. *Providing for Outstanding Science and Mathematics Students for High School.* Southern California Education Monographs, No. 16. Los Angeles: University of Southern California Press.

A detailed study of methods for providing for such students; criteria for ability grouping and special classes are discussed.

Gowan, J. C. 1957. "Dynamics of the Underachievement of Gifted Students." *Exceptional Children,* 24, 98–101, November.

Underachievement in gifted students at various grade levels is related to 13 factors.

Guilford, J. P. 1950. "Creativity." *American Psychologist,* 5, 444–454, September.

A study of creativity is badly needed; a fruitful approach is through factor analysis. Nine abilities that may apply specifically to science are listed.

Guilford, J. P. 1954. "The Nature of Creative Thinking." *Eastern Arts Association Research Bulletin,* 5, 5–9, March.

An important hypothesis underlying this work is that creative qualities are on a broad continuum and that individuals possess these qualities to a different degree.

Guilford, J. P. 1957. *A Revised Structure of Intellect.* Psychological Laboratory Reports No. 9, Los Angeles: University of Southern California.

This is the last of a series of several articles (in this report) on factor analysis of creative thinking and reasoning. It presents a composite chart of intellectual factors and representative tests for them.

Guilford, J. P., R. C. Wilson, and P. R. Christensen. 1956. *A Factor-Analytic Study of Creative Thinking, II, Administration of Tests and Analysis of Results.* Psychological Laboratory Reports No. 8, University of Southern California.

Results meaningful in work of developing science potential.

Guilford, J. P. 1959. *Intellectual Resources and Their Value as Seen by Scientists,* paper presented *3rd U. Utah Research Conference on Identification of Creative Science Talent.*
Report of studies of immediate interest to problems of working with gifted students in biology.

Hall, Theodore. 1956. *Gifted Children: The Cleveland Story.* Cleveland, Ohio: World Publishing Company.
A description of the Cleveland Public Schools Major Work program since 1922. Major work classes are scheduled in elementary, and junior and senior high schools.

Havighurst, R. 1958. *Education for the Gifted.* 57th Yearbook, Part II, National Society for Study Education. University of Chicago Press.
This book brings together the many views and ideas in this area; social factors, the gifted individual, and the education of the gifted are treated particularly.

Havighurst, R., E. Stivers, and R. DeHaan. 1955. *A Survey of the Education of Gifted Children.* Supplementary Educational Monographs, No. 83. Chicago: University of Chicago Press, November.
Includes methods of identification and teaching and descriptions of about 50 school programs at various grade levels.

Heck, Arch. 1953. *The Education of Exceptional Children.* New York: McGraw-Hill.
Problems discussed include discovery, selection, organization, curriculum, and teaching the gifted. Discussion is in general terms, not specifically related to science.

Heist, P. et al. 1961. "Personality and Scholarship," *Science,* 133, February 10.
Study of National Merit winners concluding that students of high ability attending highly productive colleges have a pattern of traits, attitudes, and values that are more related to serious scholastic pursuits than have students of similar high ability attending less productive institutions.

Henry, N. (ed). 1958. *Education for the Gifted.* 57th Yearbook, Part II, National Society for Study Education. University of Chicago Press.
This book brings together the many views and ideas in this area; social factors, the gifted individual, and the education of the gifted are treated particularly.

Hollingworth, L. S. 1942. *Children Above 180 IQ, Origin and Development.* Yonkers-on-Hudson: World Book Company. Contains records of 12 such students and analysis by the author.

Hollingworth, Leta S. 1926. *Gifted Children: Their Nature and Nurture.* New York: Macmillan.
One of the early works in the field. Gives history of testing movement, misconceptions about gifted children, and newer ideas on the "gifted child."

Hollinshead, B. S. 1952. *Who Should Go to College.* Columbia University Press.
A study of students who should attend college; reasons why many do not attend; the way in which financial aid might help conserve our human resources.

Horrall, Bernice. 1957. "Academic Performance and Personality Adjustment of Highly Selected College Students." *Genetic Psychology Monographs,* Vol. 55, February.
Follow-up study of two groups of Purdue freshmen, giving results of a battery of tests.

Interdisciplinary Symposium on Creativity. 1959. *Creativity and Its Cultivation.* New York: Harper.
Contains 15 addresses on creativity; the first is by H. Eyring on Scientific Creativity.

Kettner, N., J. Guilford, and P. Christensen. 1959. "A Factor-analytic Study Across the Domains of Reasoning, Creativity, and Evaluation," *Psych. Monographs,* 73:479.
Descriptions of 57 experimental tests selected for use in analysis of factors designated in the testing of hypotheses presented relating to reasoning, creativity, and evaluation.

Keys, Noel. 1942. "Should We Accelerate the Bright?" *Journal of Exceptional Children,* 8, 248–254, 269.
Follow-up study of acceleration and early college entrance of bright students; this is vitally important for students with IQ above 140.

Klinge, Paul. 1951. "Budding Scientists: Identifying and Nurturing Them." *Clearing House,* 26:67–71, October.
Describes plan and follow-up for teaching students in science at the Thomas Carr Howe High School in Indianapolis, Indiana.

Knapp, R. and H. Goodrich. 1952. *Origins of American Scientists.* Chicago: University of Chicago Press.
Lists institutes of higher learning particularly successful in training outstanding scientists and discusses the importance and qualities of superior teachers.

Knapp, R. and J. Greenbaum. 1953. *The Younger American Scholar: His Collegiate Origins*. Chicago: University of Chicago Press.

Lists colleges that have turned out the most young scholars and the most scientists. Discusses reasons for differences between institutions and need for encouraging intellectual potential.

Kough, Jack. 1960. *Practical Programs for the Gifted*. Science Research Associates, Inc., Chicago.

Excellent, practical suggestions with many specific illustrations for administrators and teachers who wish to improve their schools are provided. There are chapters on getting a program started, on identification of gifted, on their motivation, and significant gifted child programs in operation over the country. A list of capable consultants is given in Chapter 8.

Kough, J. and R. DeHaan. 1955. *Teacher's ance Handbook: Part I, Identifying Children With Special Needs*. C.. cago: Science Research Associates. Lists of characteristics used in identifying youngsters with scientific ability (among others).

Kubie, Lawrence S. 1954. "Some Unsolved Problems of the Scientific Career." *American Scientist*, 41, 596–613, 1953, and 42, 104–112.

Too little is known about the unconscious forces that lead a person into research or the conscious elements that determine success or failure of his efforts.

Laycock, S. R. 1957. *Gifted Children*. Toronto, Canada: Copp Clark Publishing Co., Ltd.

Review of much work in this field and specific references to some programs in the United States as well as those in Canada. Chapter 10 discusses enrichment in science and mathematics at elementary and secondary levels.

Lehman, H. C. 1953. *Age and Achievement*. Princeton, New Jersey: Princeton University Press.

A study of the age at which outstanding performance was accomplished in science and related fields (among others). The range of creative years is discussed.

Lightfoot, Georgia F. 1951. *Personality Characteristics of Bright and Dull Children*. New York: Bureau of Publications, Teachers College, Columbia University.

A study of 40 personality differences between bright (median IQ 140) and dull (median IQ 88) youngsters at the Speyer School (elementary).

Lindquist, E. F. (ed). 1951. *Educational Measurement*. Washington, D. C., American Council on Education.
A comprehensive work in the field of educational measurement. Chapters 3 and 4 on the function of measurement are of particular interest.

Lowenfeld, Viktor. 1952. *Creative and Mental Growth*, Revised. Macmillan.
Although the book is addressed to those who teach art, the descriptions of kinds of creative expression found among pre-school age to adolescent students, having meaning for teachers of science.

MacCurdy, Robert D. 1956. "Characteristics of Superior Science Students and Their Own Sub-groups." *Science Education*, 40, 3–23.
A study of significant characteristics and background factors in superior science students (winners and honorable mentions in the Science Talent Search).

Mallinson, G. and H. Van Dragt. 1952. "Stability of High School Student's Interest in Science and Mathematics." *School Review*, 60, 362–7, September.
A study of student's interests in the 9th and the 12th grades fails to substantiate claim that interest is likely to be a reliable predictor of talent.

Martens, Elise H. 1946. "Curriculum Adjustment for Gifted Children." Washington: U. S. Office of Education, Bulletin, No. 1.
Discusses methods of identification, grouping, acceleration, and enrichment for gifted students at various grade levels.

Maslow, A. H 1958. "Emotional Blocks to Creativity." *Jr. Individ. Psych.* 14.
This paper in the Journal of the American Association of Adlerian Psychology presents descriptions of good adjustment and emotion blocks to primary processes of cognizing. These are also relevant to an undertanding of creativity in future scientists.

McClelland, D., A. Baldwin, U. Bronfenbrenner, and F. Stodtbeck. 1958. *Talent and Society*. Van Nostrand.
Review of issues in talent identification; effect of social factors such as family interaction, culture values (ex. Jewish and Italian cultural patterns); review of measurements of skill in social perception.

Meister, Morris. 1953. "The Ford Foundation Experiments—Their Implications for the Science Education of High Ability Youth." *Science Teacher*, 20, 107–110, April.
Brief review of the four Ford Foundation programs involving enrichment and acceleration of high school science students.

Meister, Morris and H. Odell. 1951. "What Provisions for the Education of Gifted Students?" *Bulletin of the National Association of Secondary School Principals,* 35, 30–38, April.
Mainly a brief description of the role and function of the specialized high schools for gifted students in New York City.

Merriam, R. 1960. "Creativity, Biology and Education." *AIBS Bulletin,* June.
This timely paper offers a lucid, strong plea for *opportunities* for "research" activities that stimulate individuality and independence at the high school level.

Metropolitan School Study Council. 1956. "How to Educate the Gifted Child." Committee on Exceptional Children and the Reporters of Exchange Magazine, New York.
Includes descriptions of various classroom practices in high schools for gifted students in science, mathematic, and other areas.

Mooney, Ross L. 1954. "Groundwork for Creative Research." *The American Psychologist,* 9, 544–548.
The basic quality of creative character of scientific research is not fully understood by scientists themselves; it requires further research. Creative person seeks to focus his experiencing through self-differentiation and self-realization. This is evidenced by a willingness to be different in things that make a difference.

Murphy, G. 1945. "The Freeing of Intelligence." *Psych. Bulletin* 42.
Descriptions of factors that may affect many gifted individuals; pertinent to studies of giftedness in science.

Nason, L. J. 1958. *Academic Achievement of Gifted High School Students.* Los Angeles: University of Southern California Press.
A study of conditions which apparently influence some bright high school students (in Long Beach, California) to academic achievement higher than their equally intelligent classmates.

National Education Association. 1958. *The Identification and Education of the Academically Talented Student in the American Secondary School.* Washington, D. C.
Report of conference of identifying and educating academically talented students; one section devoted to education in science.

National Education Association. 1961. *Guidance for the Academically Talented Student,* NEA and American Personnel and Guidance Assoc., Elizabeth Drews (ed), Washington 6, D. C.
A readable book summarizing a conference dealing with the identification,

motivation of underachievers, educational provisions, and responsibilities of counseling talented students. A comprehensive appendix lists, by states, the in-school programs and summer and out-of-school programs for talented students.

National Education Association and National Science Teachers Association. 1959. *Science for the Academically Talented Student in the Secondary School.* Washington, D. C.
Report of a conference which discussed identification, content of science, methods of teaching, and the teacher of academically talented science students.

National Education Research Bulletin. 1941. "High School Methods with Superior Students." 19, 156–197, September (Vol. XIX, No. 4).
The entire issue is devoted to the study of superior students, enrichment in science is discussed.

National Manpower Council. 1953. *A Policy for Scientific and Professional Manpower.* New York: Columbia University Press.
The nation can develop the scientific manpower it needs by expanding college and university opportunities for capable young people by maintaining a steady flow of such students now "lost" in such educational institutions.

National Society for the Study of Education. 1950. *The Education of Exceptional Children.* 49th Yearbook, Part II. Chicago: University of Chicago Press.
Chapter XIV which is devoted to special education for the gifted child; includes their characteristics and methods of identification.

Newland, T. E. 1953. "The Gifted." *Rev. Educ. Res.* 23:5, 417–431.
Review of literature, problems, tests, etc. on the nature of giftedness.

Olsen, Fred. 1954. "The Nature of Creative Thinking." *Phi Delta Kappan,* 35, 198–200.
The essence of creativity lies in recognition of a disturbing element and making a mental "leap into the dark." This leap is discussed in term of Spearman's three principles of cognition.

Passow, A. H. 1957. "Developing a Science Program for Rapid Learners." *Science Education,* 41, 104–112, March.
No single formula can be developed which can be used by all schools in all classes, but an appropriate science program for rapid learners should be part of the developing science program.

Passow, H., et al. 1955. *Planning for Talented Youth.* New York: Teachers College, Columbia University.

A preliminary report of the Talented Youth Project. It suggests eight steps which can be taken in educating exceptionally talented children at various grade levels.

Patterson, Margaret. 1950. "Criterion for Scientists." *Science Newsletter,* 58:314–315, November 11.

Ten criteria by which a young scientist at the high school level may be recognized.

Peterson, O. L. and J. T. Robinson. 1959. "Creativity: Some Aspects and Implications." *Science Education,* 43, 420–427, December.

Survey of 37 papers on the nature of creativity.

Philadelphia Suburban School Study Council. 1954. "Guiding Your Gifted." Philadelphia: Educational Service Bureau, University of Pennsylvania.

Succinct statements of who they are and how to teach them from grades 1 through 12.

Pregnato, C. V. and J. W. Birch. 1959. "Locating Gifted Children in Junior High School: A Comparison of Methods." *Exceptional Children,* 25, 300–304, March.

Relative efficiency and effectiveness of seven different ways of locating gifted children.

Pressey, Sidney L. 1949. *Educational Acceleration: Appraisal and Basic Problems,* Bureau of Educational Research Monograph, No. 31. Columbus, Ohio: Ohio State University.

When accelerated students are carefully selected for superior intellectual ability, good health, and emotional adjustment, there are few maladjustments.

Roberts, Helen E. 1954. *Current Trends in the Education of the Gifted.* Sacramento, California: California State Department of Education.

Description of various programs in operation, mainly at the high school level, for gifted students.

Roe, Anne. 1953. *The Making of a Scientist.* New York: Dodd, Mead; also Apollo Editions, 1961.

Research scientists stressed the importance of individual research (even if of no great moment) in their public school experience and the importance of a good teacher.

Roe, Anne. 1951. "A Psychological Study of Eminent Biolcgists." *Psychological Monograph,* 65:331.
A clinical study of 20 eminent biologists based on life histories and three psychological tests: the verbal-spatial-mathematical test, the TAT, and the Rorschach.

Roe, Anne. 1951. "Psychological Tests for Research Scientists." *Journal of Consulting Psychology,* 15, 482–495.
Comparison of test results of a verbal-spatial-mathematical test and the Rorschach and TAT given to 61 eminent research scientists.

Rogers, Carl R. 1954. "Toward a Theory of Creativity." *ETC. A Review of General Semantics,* 11, 249–259. (Also in Conference on Creativity.)
Presents a theory of constructive creativity and seven hypotheses regarding it

Scheifele, Marian. 1953. *The Gifted Child in the Regular Classroom.* New York: Teachers College, Columbia University. Discussions of methods of identifying these students, their special problems, and provisions for the gifted in regular classrooms.

Schenberg, S. 1959. "Encouraging Talented Youngsters in Science." *High Points,* 41, 14–24, May.
Presents a description of the present science program in the elementary and junior and senior high schools in New York City.

Seashore, Harold. 1952. *The Search For Talent.* Test Service Bulletin No. 43. New York: The Psychological Corporation, February.
The Differential Aptitude Test can be used to identify at the high school level boys who will study successfully engineering, science, and pre-medical courses in college.

Sheldon, P. M. 1959. "Isolation as a Characteristic of Highly Gifted Children." *Journal Ed. Sociol.,* 32, 215–221, January.
A study of socialization of 28 students of IQ 170 or higher; the study included all such under the age of 12 who could be located in the New York area.

Shertzer, Bruce (ed). 1960. *Working With Superior Students: Theories and Practices.* Science Research Associates, Chicago.
This is a collection of excellent papers developed by the Project on Guidance and Motivation of Superior and Talented Students sponsored by the North Central Association of Colleges and Secondary Schools. There are sections on a review of the current research, on identification, on pro-

gram organization, on motivation, on the teacher, and on examples of successful programs over the country.

Stalnaker, J. M. 1959. "Realism in Meeting the Needs of Talented Students." *Exceptional Child,* 25, 217–220, January.
We can identify such youth; once identified, they should be encouraged to work and learn to their fullest capacities from the earliest school years.

Stein, Morris and Shirley Heinize. 1960. *Creativity and the Individual.* Free Press of Glencoe, Illinois.
Selective, comprehensive, annotated bibliography of papers by psychologists on problems of creative thinking as these relate to gifted individuals.

Strang, R. M. (Chairman). 1954. "The Gifted Child: A Symposium." *Journal of Teacher Education,* 5, 210–232, September.
Overview of major issues in education of the gifted; articles by Margaret Mead, Robert Roberts, Melda Davis, Paul Witty, Melita Oden, and Lewis Terman.

Strang, R. 1957. *The Adolescent Views Himself.* New York: McGraw-Hill.
Contains several self-analyses by gifted adolescents and discusses such problems as guidance, peer relationships, and social acceptance.

Subarsky, Zachariah. 1948. "What Is Science Talent?" *Scientific Monthly,* 66, 377–382, May.
Four characteristics by which (high school) students with science talent can be detected.

Sumption, Merle R. 1941. *Three Hundred Gifted Children.* Yonkers-on-Hudson, New York: World Book Company.
The history of the education of superior students has seen three epochs since 1867: flexible promotion, acceleration, and enrichment.

Sumption, Merle R. and Evelyn Luecking. 1960. *Education of the Gifted.* Ronald Press.
Selective coverage of the research on the gifted and the administration of pre-school, elementary, secondary school, and college programs.

Super, D. and P. Bachrach. 1958. *Scientific Careers and Vocational Development Theory.* New York: Teachers College, Columbia University.
Includes the findings of the Scientific Careers Project as related to the natural scientist, the mathematician, and the engineer.

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Terman, L. M. and M. H. Oden. 1959. *Gifted Children at Mid-Life*. Stanford, California: Stanford University Press.
The 35 year follow-up study of Terman's original group. This group is now in the 40–50 age bracket.

Terman, Lewis. 1954. *Scientists and Nonscientists in a Group of 800 Gifted Men. Psychological Monograph*, No. 378, 68:7. Washington: American Psychological Association.
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Though little is known about creative talent, some working hypotheses are presented that might initiate its scientific study.

Torrance, E. Paul. 1959. "Current Research on the Nature of Creative Talent." *Jr. Counseling Psych.* 6:4, 309–316 Describes U. Minnesota studies in creativity; concerned with the development of instruments for identifying creative talent from kindergarten through graduate school. Paper describes batteries of tests used, and blocks to creativity.

Torrance, E. P., F. B. Baker, and J. E. Bowers. 1959. *Explorations in Creative Thinking in the Early School* Years. IV, Bur. Educational Res., U. Minnesota.
Describes studies showing significant relationship between degree of manipulation and the quality of inventive responses in children.

Traxler, Arthur (ed). 1956. *Selection and Guidance of Gifted Students for National Survival.* Washington, D. C.: American Council on Education.
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Tyler, Leona. 1957. "Studies on Motivation and Identification of Gifted Pupils." *Rev. Educ. Res.* 27:4, 391–399.
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Describes projects sponsored by the Office of Education relating to research projects on patterns of motivation, identification, and programs for the gifted in elementary and secondary schools.

U. S Department of Health, Education, and Welfare, Bulletin No. 5, 1954. *Teaching Rapid and Slow Learners in High School.* Washington, D. C.
Includes techniques of identification, administrative provisions, and instructional provisions in junior and senior high schools.

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In addition to describing instructional practices developed for gifted students in the secondary schools of New York State, the pamphlet lists traits associated with the intellectually gifted, talented, and creative pupils.

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Collection of papers presented by scientists and psychologists analyzing variables that are functioning in creative activities; also discusses criteria of scientific competence.
Also consult Conference papers published in 1959; papers by Getzels and Jackson and by Guilford, Wilson, et. al.

Van Zelst, R. H. and W. A. Kerr. 1954. "Personality, Self-Assessment and Scientific and Technical Personnel." *Jr. Appl. Psych.* 38, 145–47.
The author summarizes the results of a self-analysis questionnaire answered

by 514 technical and scientific personnel. Personality patterns of the productive and less productive scientists do not necessarily agree with popular conception of scientist.

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A study of age at which individuals decide to become scientists and of persons influencing their decisions.

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Report of Center for Study of Higher Education at University of California on longitudinal study of entire group of National Merit Scholars and 10% sample of near winners (659 men and 259 women). On basis of Omnibus Personality Inventory and a Study of Values, gifted students seem less authoritarian and show more esthetic and intellectual interest than other students.

Wertheimer, M. 1943. *Productive Thinking,* Harper.
Clear development of his work on insight through many examples of ways children solve problems in mathematics.

Weisskopf, E. 1951. "Intellectual Malfunctioning and Personality." *Jr. Abnormal & Soc. Psych.* 46.
Survey of some of the dynamic personality factors which may handicap intellectual functioning. Although the paper focuses on abnormal personalities, it offers some understanding of "under-achievers."

Witty, Paul (ed). 1951. *The Gifted Child.* American Association for Gifted Children. Boston: D. C. Heath.
Contains 15 chapters by outstanding workers in the field. Discusses work done in identifying, studying, and teaching gifted students at all grade levels.

Witty, Paul. 1952. *Helping the Gifted Child.* Chicago: Science Research Associates.
An illustrated pamphlet on ways adults can discover and help gifted youngsters at various age levels.

Witty, Paul. 1953. "How to Identify the Gifted." *Childhood Education,* 29:312–316, March.
Consistently remarkable performance at any age level is an indication of giftedness; the climate of the classroom is an important factor in the emergence of giftedness.

Wolfle, Dael. 1954. *America's Resources of Specialized Talent.* New York: Harper and Brothers.
The book discusses the supply and demand of trained science personnel (as well as other personnel) and discusses characterisitcs of students entering various specialized fields.

Wolfle, Dael. 1951. "Intellectual Resources." *Scientific American,* 185, 42–46, September.
We must do better than before in identifying bright youngsters and in encouraging them to pursue higher education that will train them for intellectual leadership.

Wolfle, D. and T. Oxtoby. 1952. "Distribution of Ability of Students Specializing in Different Fields." *Science,* 116, 311–314.
A comparison of the AGCT scores of undergraduate and graduate students in physical science, biological science, social science, humanities, engineering, agriculture, business and commerce, and education.

Wolfle, D. 1960. "The Diversity of Talent." *American Psychologist,* 15:8, August.
Plea for need to consider students who have developed some of their talents so highly that they cannot be well-rounded. Wolfle calls this diversity within the individual.

Worcester, D. A. 1956. *The Education of Children of Above-Average Mentality.* University of Nebraska Press, Lincoln.
Book gives special attention to acceleration and enrichment from kindergarten through high school.

Wrenn, Gilbert. 1949. "Potential Research Talent in the Sciences." *Teachers College Record,* 30:5–22, January.
Everything possible must be done to stimulate bright students to do graduate work; many students capable of securing a doctoral degree in science do not continue higher education.

Zim, Herbert. 1940. *Early Science Interests and Activities of Adolescents.* New York: Ethical Culture Schools.
A study of interests of students in grades 7 through 12 and the relation of the science interests to the science curriculum.

Zim, Herbert. 1949. "The Scientist in the Making." *Science Education,* 33:344–351, December.
The early origin of science interest indicates that upper elementary and junior high school teachers can give the greatest initial help to potential scientists; senior high school teachers may fix the pattern.

APPENDIX

Useful Routines and Devices for Developing Projects, Student Seminars, and Institutes

SUCCESS in stimulating students to do individual work often depends on practices and devices which it is well to have in fairly steady routine. On the other hand, it is sometimes desirable to make use of community and regional facilities. This appendix is intended to offer suggestions for developing these routines, devices, and facilities. They are brought together under these heads:

A. A Project Room for Biology
B. Safety Precautions in the Laboratory and Project Room
C. Types of Students' Projects
D. Types of Students' Reports of Their Projects
E. Projects by Teachers: From the 1960 Science Teacher Achievement Recognition Program (STAR)
F. An Example of a Biology Seminar to Stimulate Individual Work
G. An Example of a Community Seminar Project
H. An Example of a Regional Project to Develop Superior and Talented Students
I. An Example of a National Project to Stimulate Individual Work in Biology

Appendix A

A PROJECT ROOM FOR BIOLOGY

Possible facilities and equipment for a biology project room

Laboratory tables equipped with sinks, storage cabinets, electrical and gas outlets
Storage room adjoining the project room or, if this is not possible, storage closets and shelves in the project room
Library section with book shelves, tables, and chairs
Microscopes and related equipment: compound microscopes

(some with oil immersion lenses), stereo microscopes, camera lucida, photomicrographic apparatus, phase microscope, microscope lamps suitable for critical illumination, light filters
Centrifuges: hand and electric
Incubators, ovens, and autoclave
Microtome and accessories: knife, paraffin oven, slide warming table
Still for making distilled water
pH meter
Refrigerator with variable temperature control
Colorimeter
Kymograph
Terraria and aquaria with accessories, filter, aerator, temperature control
Glassware, reagents and media
Chromatographic materials
Animal cages
Photographic apparatus—still and motion picture cameras, exposure meter, tripod, close-up lenses

For helpful suggestions on setting up a project room see "Starting a Science Project Room" by David Kraus in *Selected Science Teaching Ideas* of 1952, edited by R. Will Burnett, National Science Teachers' Association.

Appendix B

SAFETY PRECAUTIONS IN THE LABORATORY AND PROJECT ROOM

Students who work in the laboratory learn that certain safety precautions are standard operating procedure.

General

Students should not work alone in a laboratory when using a Bunsen burner, pulling glass, or etherizing animals. In our experience we have found it successful to have students submit, in advance, their order for materials for the day or week. In this way, we can plan to supervise students using burners, or engaging in other hazardous activities.

The use of sharp-edged instruments and tools should be under supervision.

An earthenware crock should be reserved for disposal of broken glass (and so labeled).

Fire extinguishers, fire blankets, and fire pails with sand should be in each laboratory and students should know how to use them. A First-Aid kit should also be in the laboratory.

Defective electrical outlets, wiring, and gas fixtures should be reported immediately for repair.

The use of radioactive materials requires special facilities and handling.[1]

Care of Animals

All living organisms should be cared for humanely in clean cages with food and water. Precautions must be taken that students do not tease animals, cause them to be frightened and nip fingers. It may be well to have students wear heavy gloves when cleaning the cages, especially if animals seem frightened or when there is a litter in the cage.

If animals are to be killed or operated upon or if blood is to be drawn, efforts should be humanely conducted so that animals do not undergo needless pain.

Chemicals

All chemicals must be clearly labeled; excess chemicals are not returned to the stock bottle. Acids, strong hydroxides, other combustible or poisonous chemicals are stored in locked metal cabinets, or on stone shelves in an area that can be locked; they are not left on open shelves.

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[1] *Teaching With Radioisotopes*, edited by H. Miner, R. Shackleton, and F. Watson, U. S. Atomic Energy Commission, Washington, D. C., 1959. $.40.

Directions for storing chemicals are given on the label. Avoid storing in proximity chemicals that react with each other.

Field Trips

Permission should be obtained from parents before the trip. Students should be familiar with the terrain so that they wear proper clothes. A small First-Aid Kit should be taken along.

Students should be taught to identify poison ivy, poison sumac, copperhead snakes, and other harmful organisms they may encounter on the trip. The possibility of some students being allergic to pollen in the area must be considered.

Appendix C

TYPES OF STUDENTS' PROJECTS

1. *Recent Projects of Some Students of Bronx High School of Science*

   Pigment production in *Serratia marcescens.*
   Algal nitrogen fixation in lichens.
   Electrophoresis of milk.
   Gibberellins and roots.
   Muskrats in Van Cortlandt Park.
   Aeroembolism; theoretical prevention.
   DNA and heredity in bacteria.
   Superovulation in mice.
   Nitrates and plant growth.
   Aureomycin as a metabolite for certain soil microbes.
2. For a *list of project ideas* see "Project Ideas for Young Biologists," Sister Agnes Aloyse Hille, S.P. 1960. *The American Biology Teacher,* 22:5, May.
3. *Students' Westinghouse Projects in Biology*

   An indication of the spread of interests of high school students may be gleaned from an examination of the listing of the titles of the Westinghouse Honors group each year by Science Service, Washington, D. C.

Examples of project papers submitted by high school students in Westinghouse Science Talent Search Examinations:

a) The Role of Luteinizing Hormone in Testicular Tumorigenesis in Balb/C Mice, Douglas Chessen, East H. S., Denver, Colorado.

b) Quantitative and Qualitative Analysis of Gases in Blood Samples by Gas-Solid Chromatography, Dennis Herrin, Anacostia H. S., Washington, D. C.

c) Embryonic Chick Heart as a Biological Thermometer, Donna Finerty, Coral Gables Sr. H. S., Coral Gables, Florida.

d) Pineal Regulation of the Water Metabolism and Behavior of *Bufo terrestris*, William Adkins, Melbourne H. S., Melbourne, Florida.

e) Molt-Controlling Hormones of Crayfish, Its Characteristics and Basis for Possible Application in Medicine, James Hosford, Northside H. S., Atlanta, Georgia.

f) Characteristics of the Flavonoid Pigments of Roses Using Paper Chromatography, Lloyd Greene, Nicholas Senn H. S., Chicago, Illinois.

g) Mutations Produced by the Irradiation of German Millet Seeds, Wayne Settle, Portland-Wayne Twp. Sr. H. S., Portland, Indiana.

h) Studies in Bacterial Mutation, Mary Sue Wilson, Malcolm Price Laboratory School, Cedar Falls, Iowa.

i) An Analysis of the Vegetation in an Abandoned Gravel Pit, Richard Ferrell, Central H. S., South Bend, Indiana.

j) Growth Patterns and Chromosomal Aberrations in Plant Cells in a Liquid-medium Tissue Culture Environment, Robert Finigan, Framingham H. S., Framingham, Mass.

k) Acetycholine Content of the Regenerating Forelimb of the Adult Newt, William Hochfeld, Bowen H. S., Chicago, Illinois.

l) Investigation of Various Factors Affecting the Perception of Vertical and Horizontal Lines, Laura Kaufman, Erasmus Hall H. S., Brooklyn, New York.

m) Effects of Adenosine Triphosphate on Cultured Leg Muscles Extracted from a *Rana pipiens,* Philip Phillips, Samuel Tilden H. S., Brooklyn, New York.

n) Effects of Varying Light Intensities on CO_2 Fixation in Plants, Betty Ann Broding, Thomas Edison H. S., Tulsa, Oklahoma.

o) Effects of Sodium Fluoride on Plants and Animals, Patricia Ann Bytnar, Sacred Heart H. S., Pittsburgh, Pa.

4. See also "*Block Programs in Biology,*" BSCS.
5. See also *High School Biology: Investigations in Biology for High School Students.* Vols. 1 & 2.

Appendix D

TYPES OF STUDENTS' REPORTS OF THEIR PROJECTS

Two reports are given by way of example: the first is an abstract of a high school student's paper; the second is a paper presented in its entirety.

1. *Digestive Processes in the Venus Flytrap, Dionaea muscipula*[1]
   by Thomas C. Emmel, 17
   Susan M. Dorsey High School, Los Angeles, Calif.

(Note: This report was presented under the following: 1. Introduction; 2. Methods and Techniques; 3. Preliminary Experiments on Digestion of Various Proteins; 4. Experiments; 5. Conclusions; 6. Summary. The Appendix contains: References Cited, Tables, Graphs, Summary of Test, Data, Color Slides, and Key to Color Slides. We quote here 2, part of 4, and 5.)

Methods and Techniques

The problem of successfully culturing the experimental plants had already been solved as the results of a previous project. In brief, the experimental plants were obtained from a biological supply house in North Carolina, the restricted locality of the Venus flytrap. Upon receipt they were planted in large flats, using a soil mixture of 50% peat moss and 50% river sand and keeping the soil moist at all times. These flats were placed in a home-constructed greenhouse, whose temperature and humidity were controlled to approximate North Carolina

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[1] Abstract of Westinghouse Science Talent Search paper prepared by Science Service, Washington, D. C.

environmental conditions. The air vents in this greenhouse were screened to prevent accidental closure of a trap by unwanted insects. Each plant and trap was identified by appropriately placed stakes using a code system.

To fill the traps, the insects or proteins were placed in the traps with a pair of forceps. Several of the trigger hairs were then touched, and the foceps were removed before the trap closed entirely.

To obtain samples for analysis, a sterile capillary tube was inserted between the closed lobes of the trap, the fluid drawn up, and then transferred aseptically to a five-milliliter test tube (sterile and plugged with cotton). The tube was kept under refrigeration until the experiments could be performed, which was always within a few hours of taking the sample. As it was necessary to take fluid from five or more traps in order to obtain from 0.05 to 0.2 ml. with which to experiment, the data reported are on pooled samples and represent averages in this sense.

When the quantities of fluid were relatively large (about 0.2 ml.), experiments were run on undiluted material; when the amounts were small, the sample was diluted 1:10 with sterile distilled H_2O.

All phases of the experimental work were recorded by photography. A Contaflex II camera with daylight 35mm Kodachrome film was used. A separate key to the photographs submitted is included at the end of the report.

The presence of amino acids was tested by paper chromatography using a solution of 40% butanol, 10% acetic acid, and 50% H_2O as the developer and ninhydrin as the indicator spray.

The direct counts and plate counts were done by standard methods.

Experiments

To ascertain whether digestion was actually taking place within the trap, amino acid analyses were done on undiluted digestion fluid collected at various times using filter paper chromatography. Nine amino acids were found, indicating definite digestion. A photograph of a chromatogram with these nine identified amino acids and one unknown is shown in slide No. 23.

The most important experiments were to determine if the bacterial population of the digestive fluid increased over the digestion period. This determination of bacterial population at specific times was accomplished through the use of plate counts and direct counts. After a series of traps had been fed, digestion was allowed to continue for a desired number of hours; then the sample was removed and taken to the laboratory. For plate counts, a medium with the following composition was used: 0.5% pancreatic digest of casein, 0.2% yeast extract, 0.2% dextrose and 1.5% agar. Dilutions of the digestive fluid in sterile distilled H_2O were made from 10^{-3} to 10^{-9}, and to 10^{-11} in some circumstances where an extremely high count was expected. Samples of the following hours of digestion were taken and plated during the course of experimentation: 0, 12, 24, 36, 46, 60, 72, 96, 108, and 156 hours. The zero time sample was obtained by swabbing the open trap surface with a sterile cotton swab which was then vigorously shaken in sterile water. It was found that the bacterial population of the digestive fluid increased markedly from less than two thousand per trap surface to over 10^{10} per ml. of fluid.

Conclusions

Visual evidence showed that digestion definitely takes place in the trap of *Dionaea* and analyses revealed that a number of amino acids are present in the digestive fluid. Whether these arose exclusively from the flies, *Lucilia caesar*, has not been determined.

Of the materials tested, the Venus flytrap digested only unsterilized substances. This led to the tentative conclusion that bacteria play a role in digestion, as the unsterilized flies and proteins could introduce large numbers of bacteria into the trap, supplementing those naturally present on the trap surface. Rejection of most proteins other than flies suggests that natural foods are necessary for a digestive reaction to take place in the trap. Trap size apparently has no relation to the time required for digestion. The quantity of digestive fluid produced is proportional to the size of the trap.

Most significantly, the great increase in bacterial population during the digestive period and the fact that only several kinds of bacteria are dominant throughout digestion, shows that bacterial action plays an important role in the digestive process. However, this does not exclude the possibility that digestion by enzymes secreted by the plant in the trap is also involved. Experiments are now being planned to determine whether enzymatic activity is definitely concerned. It is proposed to make sterile filtrates of digestive fluid collected as early as possible, before the bacterial population becomes very large, and to check these filtrates for protein-digesting enzymes.

2. *Student Report: Necrotic Tumor Extract and Phosphates* by Arthur Banner

Bronx High School of Science, N. Y. C.

Phosphorus, in the form of inorganic phosphate, is absorbed by the erythrocyte and incorporated into organic molecules at a remarkably fast rate. Through a number of possible mechanisms some of these phosphorylated compounds will decompose and the inorganic phosphate will be allowed to leak through the membrane into the surrounding medium. It has been shown by Reid and Ryan that this rate of loss is increased in cancerous individuals. It has also been shown that when dextrose and a native serum factor were present in the incubation medium, the phosphate loss was markedly increased in mice bearing large tumors. Reid *et al.* suggests as a reason for this an elaboration of a substance from the tumor that would damage some of the mechanisms controlling phosphate loss. Increased phosphate loss could be produced by an increase in any of the following: phosphatase activity, reversed glycolysis reactions, or glycolysis inhibition. Gourley has shown that ATP (adenosine triphosphate) bears a precursor relationship with the intracellular inorganic phosphate; others have shown that the stromata of intact cells contain an ensyme which acts on ATP within the cell. If ATP breakdown occurs without a normal rate of rephosphorylation a continual loss of energy would result. If this is the case in erythrocytes from cancerous individuals, it might be the cause of the anemia associated with the neoplastic diseases.

However, there is little evidence to suggest that it is the presence of a tumor alone which is causing these cells to deviate from the normal. It seems equally possible that some factor associated with tumor growth is responsible for this phenomenon. Since necrotic material by its very nature is usually associated with large tumors and since it has been shown that large mouse tumors produce a much more marked change in erythrocyte phosphate loss that smaller tumors, necrotic material might be suspected to be the causative agent. The work reported here was done in an effort to determine the effect of necrotic material, in the absence of viable tumor tissue, on the phosphate loss of hamster erythrocytes.

Hamster blood was drawn fresh each time and incubated with P^{32} at 37° C for 30 minutes. The P^{32} was carried by free Na_2HPO_4 and NaH_2PO_4 which was made isotonic with NaCl. After the period of incubation, the cells were separated from the plasma and buffer coat by centrifugation and washed four times with a phosphate buffer solution containing 8.79 gm. NaCl, 2.53 gm. Na_2HPO_4, and 0.46 gm. NaH_2PO_4, per liter. The washed cells were then resuspended in 5 ml. of the phosphate buffer. A 0.5 ml. aliquot of this suspension was made up to 10 ml. with the described buffer medium which was preheated to 37° C. The cells were thoroughly suspended and then incubated for one hour at 37° C without further agitation. At the end of this time, the cells were separated from the buffer by centrifugation and hemolyzed with 2 ml. of water; the resulting suspension was made up to 10 ml. with 18% dextrose. The radioactivity of the supernatant buffer was compared to that of the dextrose suspension, giving the fraction of the P^{32} lost during the hour of incubation.

For P^{32} measurements, 1 ml. aliquots were plated on aluminum planchettes by allowing them to dry under a stream of filtered air. The samples were counted three times each, for 15 minutes, in a gas-flow windowless radiation detector with a Radiation Counter Laboratories Mark 13, Model 3 scaler.

The animal used in this experiment was a healthy male hamster weighing 71 gm.

Anesthetization was accomplished by intraperitoneal injection of Nembutal. Under anesthesia, the thoracic cavity was opened and 1.5 ml. of blood was drawn directly from the heart into a syringe and heparinized. A 0.75 ml. aliquot of this blood was incubated with 2.5 microcuriet (mc) of P^{32} and the phosphate loss determined. The phosphate loss of normal hamster erythrocytes after one hour of incubation in a phosphate buffer solution was found to be 48.2%.

A hamster bearing an implanted muscle tumor (Myo #1 G33EFT 7815) was sacrificed by cervical separation 15 days after the tumor was transplanted. The tumor was extirpated and as much of the viable tissue as possible was dissected free of the opaque necrotic material. 1 gm. of the necrotic tissue was ground in a mortar and added to 30 ml. of isotonic saline. This suspension was then filtered through a Buchner funnel and UF sintered glass funnel in the cold room.

To determine the extract's effect *in vitro*, blood was drawn from a normal hamster weighing 71 gm. and the PO_4 loss determination made as previously described but with 0.17 ml. of the sterile extract in the incubation medium. When the erythrocytes were incubated with 0.17 ml. of a necrotic tumor extract, the phosphate loss decreased to 40.2%.

To test the extract *in vivo*, 0.5 ml. of the sterile extract was injected intraperitoneally every other day for three days into a normal hamster weighing 69 gm. One day after the final injection the erythrocyte P^{32} loss was determined in the usual manner. When the same extract was injected every other day for three days, the loss was similarly reduced to 37.7%.

In order to show some correlation between these animal experiments and human beings, determination of the phosphate loss of human erythrocytes was attempted. Stored blood was used.

It was observed by the author in a previous study that the size of the blood aliquot which is allowed to lose its phosphate into the buffer medium bears a relationship to the observed phosphate loss. When large aliquots were used, the phosphate loss appeared to decrease. This might tend to indicate that some of the phosphate which had leaked through the erythrocyte membranes was finding its way back into the cells. In this study, the author has attempted to remedy this situation by using a relatively small blood aliquot with a great excess of buffer.

It was decided to anesthetize with Nembutal since it was reliable and appeared not to have any metabolic effect on erythrocytes when compared to nonanesthetized blood samples from heart puncture. Most of the other commonly used anesthetics tend to affect the phosphate metabolism. Heparin was used as the anticoagulant because it is a normal blood constituent.

The results summarized in chart 1 and in figures 1 and 2 tend to indicate that necrotic tumor tissue produces substances which are capable of inhibiting erythrocyte phosphate loss *in vitro* as well as *in vivo*. Though it is evident that these results conflict with previous studies which showed that the presence of a tumor within the body increased the phosphate loss, we can readily explain these findings. The fact that these inhibitors can be extracted from necrotic tissue does not necessarily mean that they are released into the blood stream and play a role in the inhibition of phosphate loss. Since necrosis generally results from defective circulation in a given area of a tumor, it is probable that the capillaries would be thrombosed, blocking escape of substances from this route. In this case, material would have to escape over considerable distances by diffusion, so that the rate would bear an inverse relation to molecular size.

Though, in this experiment, there was some saline injected control, it is doubted that the saline of the extract could have caused the decrease in the phosphate loss since the P^{32} was made isotonic with NaCl and therefore was present in the normal. Possibly, the decreased phosphate loss was produced by the large molecules which were present in the extract, but probably would not be present in the blood stream. These substances might have caused a decrease in the reversed glycolysis reactions. Since phosphate is probably brought into the cell by a phosphorylation-dephosphorylation mechanism, it is doubted that phosphatase activity was reduced since there was an increase in the P^{32} uptake when the extract was present both *in vivo* and *in vitro*. It is also doubted that glycolysis was inhibited since the rate of P^{32} uptake is usually indicative of the rate of glycolysis.

Chart 1

	P^{32} Uptake*	P^{32} Loss*	% of P^{32} Lost
Normal	101.27	48.90	48.2
Necrotic Tumor Extract in Vivo	126.58	47.74	37.7
Necrotic Tumor Extract in Vitro	137.07	55.17	40.2

* Net Counts Per Minute

Since in the human erythrocyte studies, it was necessary to use stored blood, the viability of the cells was not certain. Results were obtained in which the loss varied from 35% to 63%.

When these results are made more conclusive, the author plans to dialyze the necrotic tumor extract to test the effect of the smaller molecules on the phosphate loss. He also plans to test an extract of viable tumor tissue on the erythrocyte phosphate turnover, thereby attempting to determine the actual cause of the abnormal erythrocyte metabolism of cancerous animals.

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Appendix E

Projects by Teachers: Examples from the 1960 Science Teacher Achievement Recognition Program (STAR).[1]

We have selected some topics that are biological in nature in order to give an indication of the wide interests of biology teachers in this country. The papers also give a broad picture of the kinds of practices these teachers use in the classroom with young people of different abilities who are studying biology.

"Operation Salafreeze," David Webster, Lincoln Public Schools, Lincoln, Massachusetts.

"Research in the Hinterland," Sister Mary Paulinus, O.P., St. Mary's High School, Cheyenne, Wyoming.

"Adventures in Radioactivity for High School Students," Sister Mary Hermias Mennemeyer, S.S.N.D., St. Francis Borgia High School, Washington, Missouri.

"A Student-Teacher Research Team," Harold Eddleman, Salem-Washington Township High School, Salem, Indiana.

"A Mathematical Approach to Geotropism," Harry K. Wong, Menlo-Atherton High School, Atherton, California.

"Talented Science Students Participate in a Teaching Experience," Doris Oatman, Hoover High School, San Diego, California.

"A Course of Study for Advanced Biology," Marjorie Behringer, Alamo Heights High School, San Antonio, Texas.

"The Case for the Home Laboratory," Francis St. Lawrence, Lakewood High School, Lakewood, California.

"The Advanced Science Work-Experience Program," Thomas Carlomagno, Fair Lawn High School, Fair Lawn, New Jersey.

"Ecology: The Out-of-Doors Is Our Classroom," Lola Eriksen, Mountain View High School, Mountain View, California.

[1] *STAR 1960* papers, edited by Abraham Raskin, National Science Teachers Association, 1201 Sixteenth Street, NW, Washington, D. C., 1960, page 11–15.

"World Court of Trees," Ira Finkel, Island Trees High School, Levittown, New York.

"A Presentation of Experiments for Secondary School Students in the Field of Muscle-Nerve Physiology," Frederick Avis, St. Mark's School, Southborough, Massachusetts.

"Taught, Tempered and Tested Advanced Biology," Phillip Fordyce, Oak Park and River Forest High School, Oak Park, Illinois.

"Simplified Techniques for Studying Fruit Flies," Isadore Halpern, Erasmus Hall High School, Brooklyn, New York.

"Experiments Involving Quantitative Aspects of High School Biology," Laurence Snyder, Paradise Junior-Senior High School, Paradise, California.

"An Integrated Year-Round Pupil-Teacher-Scientists Program in Experimental Biology," Meyer Gottlieb, De Witt Clinton High School, Bronx, New York; Scientist collaborator, George Snell, Roscoe Jackson Laboratory, Bar Harbor, Maine.

Appendix F

An Example of a Biology Seminar to Stimulate Individual Work (1959–1960)[1]

CELLULAR BIOLOGY

1. Endoplasmic reticulum and ribosomes
2. Golgi apparatus
3. Mitochondria, morphology and physiology
4. Spindle, centrosome, astral rays
5. Cell membrane
6. Nuclear membrane
7. RNA
8. DNA
9. Chloroplasts and plastids

[1] Seminar part of biology course, Bronx High School of Science, New York, as described in Chapter II.

10. Vacuole
11. Cell pigments other than chlorophyll
12. Nucleolus
13. Chromosomes
14. Mitosis
15. Cellular oxidation
16. Protein synthesis
17. Regulation of metabolism
18. Photosynthesis

GENETICS

1. Historical development
2. Dominance
3. Ploidy
4. Translocation and non-disjunction
5. Crossing-over, linkage, chromosome maps
6. Mutations
7. Population studies
8. Human inheritance: Physical, physiological, mental traits
9. Bacterial genetics (transduction and transformation)
10. Viral genetics
11. Sex determination
12. Origin of life

REPRODUCTION AND DEVELOPMENT

1. Parthenogenesis
2. Parthenocarpy
3. Embryology of flowering plants
4. Mechanisms of fertilization—adaptations
5. Early development of animal embryos
6. Post gastrula development in amphibia, birds and mammals
7. The problem of differentiation

These topics represented outgrowths from the enriched basic course in biology in which all of the seminar participants were enrolled.

Appendix G

A COMMUNITY SEMINAR PROJECT

One example of a program in which industry stimulates the use of a seminar method using th resources of the community.

An Action Program in Science for Superior and Talented Students[1]

by Jacob W. Shapiro
Coordinator, the Joe Berg Foundation
Chicago, Illinois

How would you like to teach a class of ninth-grade boys and girls with most or all of the following characteristics:

1. IQ of 135 or over
2. College sophomore reading comprehension and vocabulary level
3. Achievement test scores in the 95th percentile or above
4. School performance at the honor-roll level or above
5. Demonstrated high motivation in science and mathematics

Probably you would answer in the affirmative—that you would like to teach such a class. But since there are only 168 hours in a week, wouldn't you also hesitate to take on such a responsibility? So much more time seems to be required to stimulate and challenge a class of 25 such youngsters.

This is the problem: How can we provide adequate educational experiences for these superior and talented students when teachers are already overburdened and when most other citizens have more activities than they have time for? Here is a partial solution: Multiply time by vitalizing already existing community assets and harnessing them in a co-operative effort involving the gifted child, his parents, trained laymen, the school, industry, and industry's laboratories.

This solution is the basis of the Plan for the Advancement of Science sponsored by the Joe Berg Foundation.[2] The Joe Berg Foundation sponsors seminars which, at practically no cost to anyone, provide extracurricular educational experiences for gifted students. These seminars offer science instruction that is more advanced, rigorous, and individ-

[1] From Shertzer, Bruce (ed.). 1960. *Working with Superior Students,* Science Research Associates, 295–301.

[2] For descriptive material, write to Joe Berg Foundation, 1712 S. Michigan, Chicago 16, Ill.

ualized than that provided in the regular curriculum. The instruction is especially meaningful, because the seminar staffs are made up primarily of volunteer trained laymen employed by industry in the fields of research and technology.

Establishing a Science Seminar

Here are the steps involved in the process of setting up a science seminar in a given community:

First, consult governing school authorities and obtain permission to start a seminar. Second, discuss the idea with school personnel, representatives of local industry, and interested laymen. Then form a planning committee to proceed with organization of a seminar.

The first order of business for the planning committee will be to select two co-ordinators, one from the school system and one from industry. Other working committees should then be established and placed under the general direction of the co-ordinators. All committees should include teachers, interested laymen, professional men and women in the community, and school administrators.

The Joe Berg Foundation has found the following committees helpful in establishing a science seminar:

1. Advisory or steering committee to establish policy and to give general direction to the program.
2. Staff recruitment committee to locate sufficient personnel to form a staff with a student-teacher ratio of one-to-one.
3. Admissions and standards committee to set up the requirements for admission of superior students to the program and for their retention in the program.
4. Physical facilities committee to locate, at no cost to the school, places and equipment needed for students to work on their projects.
5. Projects committee to counsel the youngsters in selecting their projects and to see that their experimental work is carried out under safe conditions.
6. Public relations committee to handle communications with the general community and with other schools.
7. Curriculum committee to develop a curriculum for the program

The science-mathematics seminar should not take up the material covered in a recognized science or mathematics course. Rather it should explore advanced areas of thought and stimulate the talented student's interest in specific areas of science and mathematics.

Topics frequently discussed in seminar programs include the Bohr atom, the periodic table, digital computers, living molecules, the structure of organic molecules, the theory of relativity, carbon dating, optics, statistics and probability, solid-state physics, and the basis for modern science.

Typical Seminar Outline

The outline that follows is typical of the advance lesson plans that are made for seminars. Copies of the outline are distributed to the members of the seminar far enough in advance for them to make adequate preparation.

School District of Abington Township, Abington, Pennsylvania
Date: Thursday, May 7, 1959
Place: Abington Senior High School
Topic: Solid-State Physics
Program Chairman: John E. Remick, Manager, Technical Division, Philco Corporation
Speaker: John W. Tiley, Engineering Group Supervisor G/I Division, Philco Corp., Philadelphia

Outline of Program

1. The structure of solids
2. Insulators and conductors
3. History of Semiconductors
4. Transistors
5. Fifteen-minute film (color) on laboratory techniques in transistor technology
6. Transistor under the microscope
7. Discussion-question period

References

1. *Introduction to Solid State Physics*, Charles Killet (John Wiley and Sons).
2. *Proceedings of the Institute of Radio Engineers*, Vol. XLVI, No. 6, June 1958.
3. *Fundamental Principles of Physical Chemistry*, C. F. Prutton & S. H. Marron (Macmillan Co.).
4. *Procedures in Experimental Physics*, John Strong (Prentice Hall Co.).

5. *Proceedings of the Institute of Radio Engineers,* December 1953, pp. 1702–1720.
6. *Holes and Electrons,* William Shockley (Bell Laboratories Technical Series).

(Editor's Note: Other seminars list readings in preparation for seminar meetings. Lack of space prevents inclusion of other examples.)

Some Typical Projects

The following projects are typical of those undertaken by seminar students:

Construction of an electronic digital computer
Gas chromatography
Building a short-wave radio receiver
Examination of the side effects of tranquilizers
Design of an optimum automobile turn indicator
Mechanics of corrosion
Preparation and study of brass alloys
Preparation and molding of plastics
Measurement of an individual's information-processing ability
Effects of stathmokinetic agents on planarian reconstitution: nitrogen mustard and maleic acid hydrazide

Variety of Community Patterns

Whether the seminar plan operates in a rural or urban community, in a public, parochial, or private school, and whether it is initiated by a teacher, parent, civic leader, or industrial magnate—it works!

In Neodosha, Kansas, a one-industry rural community about 115 miles from Wichita, the program is now entering its second year. Fifteen boys and girls are working on special projects including such studies as: A Survey of Common Arthropods of Wilson County, The Effects of Chlorpromazine on Rats, and A Study of Gyroscopic Motion.

Lorain County, Ohio, has set up two seminar units for students selected from 17 schools; and 60 instructors, both men and women, have been recruited from the county's 15 major industries.

In Westmoreland County, Pennsylvania, five seminars serve more than 20 neighboring school districts.

In El Paso, Texas, and Louisville, Kentucky, the programs were introduced to the school authorities by the local Rotary Clubs. Similarly, Junior Chamber of Commerce units have been instrumental in the organization of many successful groups, notably those in Jeffersonville and Hammond, Indiana. A local businessman helped to bring the plan to Savannah, Georgia. In Gary, Indiana, a newspaper editor initiated the program.

Too numerous to mention are the communities in which alert science teachers a: d school administrators have taken the initiative not only in establishing programs in their own schools, but also in calling them to the attention of their colleagues in other communities.

In Flint, Michigan, all eight Catholic high schools joined forces to organize a seminar; the Catholic schools of Cleveland followed suit.

Evergreen Park, Illinois, and Annapolis, Maryland, were among the first to set up seminars that included students selected from adjacent public, private, and parochial schools. This pattern is now being followed in a number of places.

Appendix H

An Example of a Regional Project to Develop Superior and Talented Students

The Superior and Talented Student Project was launched by the North Central Association of Colleges and Secondary Schools in 1958 and is supported by a grant from the Carnegie Corporation of New York.[1] A program of action research on problems of motivation and guidance of able students has been initiated in 100 schools in the 19 states that are associated with the North Central Association.

In the 100 schools under study, 18,000 students were identified as ranking in the upper 25% based on national norms in tests of mental ability and/or achievement that were given in 1958–1959. In the individual schools of this STS project, as it is called, three administrative techniques are in use: ability grouping, enrichment, and acceleration. Descriptions of how the comprehensive testing and guidance programs are administered together with fruitful ideas for winning both staff and community cooperation are available.[2]

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1 *Practical Programs ,.r the Gifted*, J. Kough. 1960. Science Research Associates, Chicago, 46–47.

2 Shertzer, Bruce. 1960. *Working With Superior Students*, Science Research Associates.

Appendix I

An Example of a National Project to Stimulate Individual Work in Biology

In 1959 the National Science Foundation approved 116 summer institutes for science students enrolled in high schools throughout the country. The following is a brief description of the operation of the 1959 summer institute in botany held at the New York Botanical Garden.

Duration: Five weeks, July 6–August 7.

Daily schedule: 9 A.M.–12 P.M., 1–3 P.M., Monday-Friday. Morning sessions were devoted to laboratory exercises, demonstrations, or short field trips. Afternoon sessions provided lectures given by the Garden Staff or by invited guests. Formal lectures were followed by informal discussion periods.

Program: The program was designed to give the students orientation in and first-hand experience with certain fields of botany. The program included an introduction to the botanical and horticultural sciences, morphology, taxonomy, plant geography, ecology, mycology, microbiology, plant physiology, plant pathology, and floriculture.

Unique features of the program included:

1. The New York Botanical Garden's outstanding collection of living and preserved plants.

2. The library and laboratories provided a basis for first-hand contact with high-level botanical endeavors.

3. Field trips, taken to local and distant areas, offered opportunity to study plants in a variety of ecological situations.

4. Outstanding guest lecturers, in disciplines not covered by the Garden Staff, were invited to participate. The lecturers and their subjects were: Dr. L. G. Nickell, Chas. Pfizer & Co., "Pharmaceutical Aspects of Botany"; Dr. James L. Brewbaker, Brookhaven National Laboratories, "Cytogenetics"; Dr. Bruce Voeller, The Rockefeller Institute, "Experimental Morphology"; Dr. Karl Maramorosch, The Rockefeller Institute, "Virology"; Dr. Werner Braun, Rutgers Institute of Microbiology, "Applied Microbiology."

5. The laboratories of the New York Botanical Garden afforded a diversity of plant study experiences: taxonomical, physiological, mycological and microbiological. Students learned modern techniques

relating to each field through selected experiments relating to specific phenomena. For example, the use of microorganisms such as *Euglena* for bioassays of vitamins; study of herbarium specimens of cultivars of *Manihot esculenta* to study the intraspecific variation in plants.

6. Students were given hand lenses and individual copies of Gleason, "Plants of the Vicinity of New York," Fernald "Gray's Manual," 8th ed., and were instructed in the use of these "tools."

The inter-relatedness of the various disciplines was constantly emphasized, each lecturer and laboratory leader stressing the fact that a broad knowledge is fundamental to specific studies.

The institute had a dual directorship; a high school science chairman and a member of the science staff of the New York Botanical Garden. This arrangement permitted flexibility of the day-to-day operation of the program by an interchange of experience and ideas between the teaching staff and the high school director and broadened the base of the operation.