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ABSTRACT

The paper discusses the mathematics and science education of gifted students in grades 7 through 12. Characteristics of students gifted in science and mathematics are described: identification procedures reported in the literature are reviewed including general approaches and those specific to math and science; teaching methods involving differentiation are discussed; and suggestions are listed for program design, components, and organization aspects. Among appendixes is a listing of science and mathematics materials for the gifted. (CL)

EDUCATION FOR THE GIFTED IN SCIENCE AND MATHEMATICS

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EDUCATION FOR THE GIFTED IN

SCIENCE AND MATHEMATICS

Purpose

:s paper explores the education of gifted students in areas of science and mathematics. As part of this discussion, four major concepts will be developed:

1. Characteristics of the gifted in science and mathematics
2. Identification procedures for selecting gifted students in science and mathematics as reported in the literature
3. Instructional strategies in science and mathematics for the gifted
4. Program suggestions for the gifted in science and mathematics, Grades 7 - 12

Five subconcepts to be developed are general characteristics of the gifted, general identification procedures for the gifted, key elements of a program for the gifted, and desirable characteristics for teachers of the gifted.

Additionally, the Appendix will provide a list of science and mathematics curricula and other materials identified from the literature as appropriate for the gifted. A bibliography of professional references will also be included.

Characteristics of the Gifted

General Characteristics

Analysis of the characteristics mentioned throughout the literature reveals three major divisions: cognitive domain, affective domain, and physical data. Included in these are two ostensible categories: objective, or measurable, and subjective, or nonmeasurable. Characteristics for which empirical data can be collected are designated objective. Examples include I.Q. scores, measurable ability to learn fast, and body weight. Characteristics for which empirical data cannot be easily collected are designated subjective. Examples of subjective characteristics include high ideals, clear expression of ideas, and attractiveness.

The subsections which follow list characteristics of the gifted in each of the three classifications described above. The list is not meant to be exclusive nor all encompassing; rather, it represents the suggestions of pundits in gifted education. Every gifted child may not exhibit all the characteristics, but as a group, they do.

Objective characteristics within the cognitive domain are shown below. Gifted students

1. Have high I.Q.s
2. Have a large vocabulary
3. Can form and apply concepts
4. Can generalize
5. Can analyze
6. Can learn inductively
7. Can evaluate
8. Can understand the abstract
9. Can think hypothetically and deductively
10. Comprehend cause-and-effect relationships
11. Propose many solutions to problems
12. Learn fast
13. Remember well
14. Read well.

Subjective characteristics within the cognitive domain are shown below. Gifted students

1. Express ideas clearly
2. Have insight into problems
3. Can learn by complex methods rather than by rote
4. Are keen observers
5. Read a lot
6. Are intellectual leaders.

Since all characteristics in the affective domain are measured through subjective instruments such as rating scales, questionnaires, and value judgments, they are designated subjective. Affective characteristics of the gifted are shown below. When compared to others, the gifted

1. Have a higher interest in books
2. Have high ideals
3. Boast less
4. Cheat less
5. Are more trustworthy
6. Are more self-critical
7. Are not snobbish
8. Are more curious
9. Are more interested in intellectual tasks
10. Have a wide range of interests
11. Prefer games played by older children
12. Exhibit less sex preference when choosing playmates
13. Lose interest in childish games early
14. Enjoy quiet games that require thinking
15. Have high vocational aspirations
16. Have realistic vocational aspirations
17. Are interested in the environment
18. Are concerned about world problems and issues
19. Set high standards for themselves
20. Have unusual imaginations

21. Are better socially adjusted

22. Have common sense

23. Have a longer attention span

24. Work independently

25. Have a mature sense of humor.

Objective physical characteristics are shown below. When compared to others, the gifted

1. Are taller
2. Are heavier
3. Are stronger
4. Undergo bone ossification earlier
5. Reach puberty earlier

Subjective physical characteristics are shown below. When compared to others, the gifted are

1. Healthier
2. Superior in mental health
3. Better physically developed
4. Coordinated.

Characteristics Related to Science

The characteristics of the gifted in science have been studied, discussed, and speculated on in recent years. The status of this effort is perhaps best summarized by Lesser (Gold, 1965). Lesser stated that there is disagreement about an open mind about religion. Perhaps the most important characteristic she describes is one referred to as questing. The questing student is one who is not satisfied by the status quo of explanations regarding encounters with objects and occurrences. The questing student does not take authoritarian information sources as the last words, but continues to search for answers.

Paul Witty (Henry, 1958) describes the recognition, identification, and characteristics of the gifted. Among others, the characteristics of the gifted high school science student are described. They range from a desire to go to college to being the youngest in age of students in their same grade. Characteristics useful for the identification of such students were described as having a knowledge of the fundamentals of arithmetic and spelling, reading avidly, studying a great deal, showing devotion to personal study or hobbies, being in excellent mental and physical health, and having an I.Q. of around 140. Witty concludes by saying,

> "potentially gifted pupils in the area of science are typically characterized by high verbal ability, high mathematical ability, and superiority in various aspects of science which may be revealed on tests. But they are characterized also by 'drive' or determination to use their abilities as well as by a searching, inquiring attitude. And they are, of course, interested in various aspects of science." (Henry, 1958, pp. 53-54)

After discussing a process for identifying the gifted, Kough (1960) described methods for identifying special talents or disabilities. Kough and DeHann (Kough, 1960, p. 26) list 10 behavioral characteristics of the student with scientific ability:

1. Expresses himself clearly and accurately through either writing or speaking.
2. Reads one to two years ahead of his class.
3. Is one to two 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 fine, precise manipulations.
6. Is willing to spend time beyond the ordinary assignments or schedule on things of interest to him.
7. Is not easily discouraged by failure of experiments or projects.
8. Wants to know the causes and reasons for things.
9. Spends much of his 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.

J. Stanley Marshall (Fliegler, 1961) reiterates the stereotypic view of the gifted science student dispelled by the Terman studies. As a group, the gifted in science are not sickly, do not wear glasses, and do not devote their time to working and studying alone. As a group, such students are the antithesis of that picture. Characteristics that Marshall points out are exceptional ability in mathematics, an interest in quantitative relationships, curiosity, being an avid reader of science books, preoccupation with projects, desire to write about science-related topics, and what Roe describes as questing. In addition, he includes a checklist of 21 characteristics for identifying the gifted in science. Although Marshall's list was originally meant for elementary students, Brandwein includes it in his paper (1975) "Teaching Gifted Children Science in Grades Seven Through Twelve," commenting that high school students exhibit the same characteristics. The checklist is shown below.

A Checklist for Identifying
Gifted Children in Science

Interest in science during the pre-school years.

Curiosity as to what makes things work.

Ability to understand abstract ideas at an early age.

Strong imagination in things scientific.

A love of collecting.

Abundance of drive -- willingness to work on a science project for long periods of time in the face of difficult obstacles.

Better-than-average ability in reading.

Better-than-average ability in mathematics.

Unusual ability to verbalize ideas about science.

High intelligence, I.Q. of 120 or more.

Tendency to think quantitatively -- to use numbers to help express ideas.

Willingness to master the names of scientific objects.

Willingness to pass up sports and other games in favor of scientific pursuits.

Tendency to relate stories about science, including the writing of science fiction.

Creativity in science projects, including writing.

Evident discontent with reasons which other children readily accept for things scientific.

Unwillingness to accept explanations about things scientific without proof.

Exceptional memory for details.

Willingness to spend long periods of time working alone.

Ability to generalize from seemingly unrelated details.

Ability to perceive relationship among the various elements in a situation.

(Fliegler, 1961, p. 137)

In the same publication (Fliegler, 1961) Collette and Burdick describe the gifted science student in the secondary school as one who has an I.Q. of 120 and above and also cite a list of characteristics by Brandwein: A tendency toward individual sports, a significant time spent on intellectual activities, involvement in self-initiated projects, a tendency toward sophisticated pastimes and the reading of serious magazines, a tendency to attend the theater, involvement in discussion-type school-sponsored clubs and activities, a tendency to buy books, a tendency not to be a school disciplinary problem, being a member of an educated family, a tendency to be introverted.

Collette and Burdick further comment (p. 158) that the gifted science student might, because of specialized interests in a specific science field, be knowledgeable about selected topics and uninformed about others. Such students might neglect other academic areas, "sometimes regarding them with a shade of contempt."

Brandwein (1975) discusses the characteristics of the gifted in junior and senior high school. A major portion of that discussion includes Marshall's checklist, cited in this paper. Brandwein clarifies the listed characteristics by saying that the gifted high school science student maintains varied interests, has developed many skills, is involved in numerous activities and hobbies, and maintains a sustained interest in science.

Kopelman et al. (1977) describe the Bronx High School of Science in New York, a specialized school for the gifted. Students who attend must pass entrance examinations and have the recommendations of their ninth grade science teachers. Twelve characteristics of students described as creatively gifted in the sciences are provided and are based on observations of participating students:

1. They are strongly and sincerely motivated to learn and achieve in science.
2. They are able to work well independently in the laboratory, the library, and the classroom.
3. They are curious about phenomena.

4. They are very much interested in getting answers to questions suggested by their work and their teachers.

5. They ask many questions.

6. They are stimulated by problem-solving approaches to learning.

7. They are good at identifying significant problems in a mass of information.

8. They are readily able to induce, deduce, and make connections between related ideas.

9. They often see different approaches or come up with offbeat ideas.

10. Their creativity and achievement extend to many other areas.

11. They relate well to their peers and elders.

12. Many of them have long-term goals well established.

(p. 82)

Recently, the Office of Education for the Gifted and Talented of the U.S. Department of Health, Education, and Welfare compiled a list of guidelines that indicate scientific ability ("Does Your Child Have Scientific Ability?", 1978). Although meant primarily for elementary school students, they closely follow the characteristics described in this section. The guidelines are summarized as follows: good motor coordination, devotion to investigations and personal projects, persistence despite failure, interested in cause-and-effect relationships, a tendency to read science-related material, and enjoyment of scientific discussions.

Up to this point, the paper has discussed characteristics of the gifted in science in terms of behaviors, proclivities, abilities, and persistence. The Study of Mathematically and Scientifically Precocious Youth, now known as Study of Mathematically Precocious Youth (SMPY), was initiated in 1971 to study extreme giftedness systematically. Students are first eligible to participate during grades 7 and 8 and undergo a battery of tests and informal observations. (Consequently, many aspects of the gifted studied by Terman and associates have been reexamined.) This study has produced up-to-date information on gifted students in mathematics and science in areas such as cognitive abilities, achievement, personalities, values, occupational interests, and behaviors. Studies that have particular significance for science education are described below. Other studies are described in "Characteristics Related to Mathematics," which follows.

In two separate studies, gifted students aged six through twelve (Webb, 1973) and in grades 5 and 7 (Keating, 1973) were evaluated on concrete and formal operational tasks. In the first study the oldest gifted students passed the formal operational tasks involving hypothetical-deductive reasoning and proportional thinking. In the second study gifted students in grades 5 and 7 passed formal operational tasks involving hypothetical-deductive reasoning, proportional thinking, and separation and control of variables. These data suggest that identified gifted students at or approaching the junior high age display developmental precocity on formal operational tasks. This is important for science education, considering Lawson's work (1974) showing that success on formal operational tasks is significantly correlated with understanding science concepts.

In light of these studies, it can be postulated that the gifted in science at the postelementary level are capable of some components of formal operational thought. An interesting speculation, based on this conclusion, is that the secondary gifted student displays all or many of the 12 major components of formal operations described by Sund (1976): hypothetical reasoning, deductive reasoning, proportional thinking, separation and control of variables, combinatorial logic, comprehension of allegory, propositional thinking, acceptance of assumptions, reflexive thinking, conceiving of Utopia, questioning authority, and accepting decisions by consensus.

The consensus of the investigators cited in this section regarding the characteristics of the gifted in science is that there is such a thing as scientific aptitude. However, although the listings of the component characteristics differ with the investigator reporting, analysis reveals an intersection of several characteristics: the gifted in science are questing students, looking for new and better explanations of the world they live in. They possess many skills that enable them to process information and observations successfully. These include high verbal and mathematical ability, excellent reading ability, the ability to grasp abstract concepts, and many mental processes characteristic of Piaget's formal operational stage. The gifted and talented are interested in learning more; this is evidenced by their devotion to projects and personal study. They seem to exhibit scientific literacy as described by the National Science Teachers Association ("NSTA...."1971). They are interested in cause-and-effect relationships, read and discuss science-related material and topics, and maintain a longstanding interest in science.

Characteristics Related to Mathematics

Descriptions of the gifted in mathematics are readily available. Like the descriptions of the gifted in science, they differ from one another but in general correlate highly with the characteristics of the gifted in science. Once again it should be pointed out that no student has all the characteristics on a given list. A student who exhibits all the characteristics of a given list is rare indeed. However, as a group, gifted students are described in a general sense by the listed characteristics.

Some time ago the National Education Association began a series of brochures entitled What Research Says to the Teacher. One brochure subtitled Teaching High-School Mathematics (Fehr, 1955) contains a brief description of mathematics for the gifted. The gifted in mathematics are described as students who have unusual abilities in the following areas: ability to manipulate and create abstractions, extraordinary memory, ability to make generalizations, ability to apply mathematical principles to other situations, curiosity, goal-directedness, persistence, insight into problem solutions, and creativity in solving problems. Additionally, they typically have a "high vocabulary with facility of expression" (p. 29).

Grossnickle (Fliegler, 1961) discusses arithmetic programs for the gifted. Although these programs are meant primarily for elementary students, he describes characteristics of the gifted in mathematics. In addition to citing a general propensity to analyze quantitative situations, he lists six characteristics: an I.Q. of 120 or more, an extraordinary memory for mathematical concepts and principles, the ability to generalize quantitative situations, resourcefulness in solving arithmetic problems, keen quantitative insight into numerical relationships expressed in verbal problems, and an advanced knowledge of mathematics. Additionally, he generalizes a definition of the gifted by Paul Witty, saying, "Any pupil is gifted in arithmetic who shows a very superior achievement in that subject" (p. 60).

In fall 1967 the School Mathematics Study Group sponsored a conference on mathematics for the gifted (A Conference on Mathematics for Gifted Students, 1967). In his conference paper on characteristics of the gifted, Frederick J. McDonald describes students who are mathematically or quantitatively gifted. In addition to general intellectual ability, as determined by standardized tests, he points out that the gifted learn quickly, have high conceptual ability, and are able to interrelate ideas. He cautions the reader that such students may not be interested in interrelating ideas nor in high-level achievement in mathematics.

The Study of Mathematically Precocious Youth, described earlier, contributed to a better understanding of the gifted in mathematics. As a result of the administration of an SMPY questionnaire it was found that the extremely gifted in mathematics expressed a dislike for school. It was further noted that this followed informal discussions with the students. "They reported a disillusionment with school in particular and academic pursuits in general" (Stanley et al., 1974, p. 30). As a check against this measure the California Psychological Inventory (CPI) was administered. This measure showed that the students were not subject to disabling inter- or intrapersonal weaknesses. Consequently, it was concluded that these students were not maladjusted but were unhappy with their educational situations.

Further analysis of the student's profile based on the CPI revealed that the mathematically gifted are "solid, competent individuals who seem to be handling their extraordinary talents in a commendable fashion" (pp. 135-136). Weiss et al. (Stanley et al., 1974) conclude by saying that these students are independent, quick, sharp-witted, foresighted, versatile, and intelligent and display unusual initiative and direction in the mathematical field.

As discussed earlier, Webb (1973) and Keating (1973) demonstrated that the gifted in science and mathematics exhibit at least some formal operational skills. Since studies by Lawson (1974) and Howe (1974) indicate that formal operational capacity facilitates understanding and retention, it can be stated that giftedness in mathematics is due in part to these advanced developmental abilities.

Krulik and Weiss (1975) discuss the teaching of mathematics from a variety of perspectives. In a chapter dealing with individual differences a discussion of the rapid learner appears. An extensive description of the gifted in mathematics precedes appropriate pedagogical techniques, suggested resources and curricular materials, and desirable teacher characteristics.

Among the characteristics of the gifted in mathematics are abilities in making abstractions, understanding and mastering concepts, and transferring knowledge to other situations. Such students enjoy in-depth examinations of topics. This fosters the investigation of several solutions to problems, a long attention span, and a desire to learn for the sake of learning. In addition, these students possess an advanced conceptualization of mathematical principles, which facilitates insight into solutions, enables them to select the best way to solve a problem, and often allows the solving of problems by intuition without an understanding of why the answer is correct. Characteristics typical of gifted students in other areas are that they read well, are curious, and are rapid learners.

As reported in this section, a number of investigators have attempted to describe the gifted in mathematics. Although each investigator emphasized varying characteristics, many characteristics appear repeatedly. Inspection of these lists reveals the gifted in mathematics to be equipped for high-level school performance. This is evidenced by a high I.Q., high performance on standardized tests, and advanced abilities in reading, vocabulary, and expression. The gifted in mathematics possess many cognitive skills that promote their performance in quantitative understandings and manipulations. They can think abstractly, interrelate ideas, make generalizations, apply learning to other situations, and perform at least partially at the formal operational level; and they have excellent memories. These competencies facilitate insight into problems and their solutions. The learning style of the gifted in mathematics favors independent study, fast-paced instruction, and minimal illustrations and examples. Their interest in learning is confirmed by an unusual knowledge in mathematics, initiative to explore topics in depth, and goal-directed activities in the quantitative fields. The gifted in mathematics are similar to the general gifted population in their curiosity, resourcefulness, and creativity.

Remarks

The gifted in science and mathematics are remarkably similar. They possess many advanced skills and abilities. They are curious and investigative and enjoy pursuing topics in depth. Their personal initiative is evidenced by their independent study of topics of their own choosing. These characteristics, as well as the ability to learn rapidly, strongly suggest that the gifted in science and mathematics require differentiated instruction commensurate with their abilities and interests, as well as appropriate programming. First the gifted students must be selected for such a program. This implies a suitable identification procedure. These aspects of meeting the needs of the gifted in science and mathematics are discussed in the sections that follow.

Identification of the Gifted

General Procedures

The selection of gifted students should do more than pinpoint the superior student who is recognized by every teacher. The procedure should also insure the selection of the gifted student who does not conform to the picture of the well-behaved A student. Further, the procedure should not overlook the gifted student who is not achieving in school because of a variety of reasons or the one who does not perform well on tests. Most important, the identification procedure should be one that overcomes cultural, ethnic, racial, and sexual discrimination.

The best insurance for identifying all bona fide gifted students is the use of a multidimensional procedure incorporating a variety of measures and indicators. This procedure should be stepwise, involving screening, identification, and selection. Such an identification procedure is intended to overcome limitations endemic to any one specific indicator.

Screening is the first step toward identifying any group of gifted students. The purpose of screening is to establish a pool of students who may be gifted. It includes group test scores; teacher, parent, and self-nominations; rating scales; and other measures designed to determine whether the student may have potential. Efforts should be made to include marginal students, especially if they are culturally, ethnically, or racially different.

Identification is the second step for selecting gifted students. It involves examining the pool of potentially gifted students and designating the gifted within the pool. Identification procedures generally involve individualized intelligence scores, case studies, and opportunities for performance that allow students to demonstrate their exceptional abilities. This step results in a group of students who are gifted but who have varying educational needs and interests.

The final step is establishing an educational plan for each student that is based on specific needs and interests. It is at this point that the characteristics of the gifted in science and mathematics, described earlier, should be considered, as well as demonstrated aptitude and interests in those academic areas.

When choosing an identification procedure it is important to consider effectiveness and efficiency. Pegnato and Birch (Barbe and Renzulli, 1975) define these terms: effectiveness is the percentage of gifted students the procedure locates, and efficiency is the ratio between the total number of students the procedure refers for individual examination and the number of gifted students found among those referred.

The ideal objective of any identification procedure is to have a highly effective and highly efficient record. The realistic balance between these aspects can be determined by deciding how completely the identification procedure fulfills the following two statements:

1. It should find as many gifted students as possible.
2. It should be cost effective, resulting in the designation of a large number of gifted students from those referred for individual examination.

Zettel (Passow, 1979) describes various state provisions for the gifted. In one subsection he discusses the identification of the gifted who have specific academic aptitudes. As might be expected, methods and procedures differ from state to state. The most common practice involves the use of a standardized aptitude or achievement test. Selection criteria range from a minimum score of the ninety-fifth percentile to one standard deviation above the national norm with a modal criterion of the ninety-fifth percentile. As an illustration he describes Idaho's selection criterion: ninety-eighth percentile on the verbal and/or performance scores on one of a number of tests such as the Cognitive Abilities Test (CAT), Diagnostic Arithmetic Test (DAT), SRA Achievement Series (SRA), Stanford-Binet Intelligence Scale, Iowa Tests of Basic Skills (ITBS), Illinois Test of Psycholinguistic Abilities (ITPA), or Metropolitan Achievement Test. Scores on appropriate subtests are also considered.

A number of programs for the gifted in science and/or mathematics are described in the literature, and many of the reports discuss the identification of students. A selected number are described in the following two sections.

Science Programs

The Talcott Mountain Science Center for Student Involvement (TMSC) is an ongoing facility devoting approximately 30% of its efforts to the gifted (Atamian, 1977). Begun in 1966 under an ESEA grant, it continues as a private nonprofit educational facility. For the TMSC Saturday program and summer program, students are selected from the group of applicants by I.Q. scores, standardized achievement scores in science and mathematics, school grades in science and mathematics, and recommendations. For readmission to a second session (semester or summer) the students' past work at the center and most recent school grades are examined. No specific minimum test scores or grades are cited as necessary for admission; the center accepts the students with the highest ones.

During the summer of 1969 the National Science Foundation sponsored a gifted science program for high school seniors at TMSC. The program was a pilot test of the Research Team Approach to Learning (ReTAL) model for developing critical and divergent thinking (DelGiorno, 1977). The selection criteria were a prerequisite of two years of algebra and one of geometry, A grades during the tenth and eleventh grades for all courses in science and related fields, junior class rankings in the upper 5%, and scores on the Binet and Wiechler Intelligence Scale for Children (WISC) of over 135. Additionally, each student was required to have recommendations from science department chairpersons, counselors, and principals. With the application, each student was required to send a written discussion of reasons for wanting to attend the program and describe his/her area of scientific interests. Again, acceptance was competitive.

During the 1974-75 school year a pilot study was conducted to determine the feasibility of using the fast-paced SMPY model developed at Johns Hopkins University (described earlier in this paper) for science classes (Cohn, 1979). Participating students were in the seventh and eighth grades. The program consisted of a class combining algebra I and II, taught in conjunction with a physical principles class. The identification procedure was based on performance on two tests: Academic Promise Test, verbal and numerical sections; and the Sequential Tests of Educational Progress (STEP) Science Series II General Science Test. The selection criterion was at least the ninety-fifth percentile on the verbal and numerical sections of the Academic Promise Test and the fiftieth percentile on the STEP test.

The Bronx High School of Science (Kopelman et al., 1977) houses another ongoing program for the gifted. Incoming ninth graders must pass an entrance examination. Sixty gifted students from approximately 400 are selected for honors courses each year for grade 10. Grade 11 students are selected from the previous year's class. Selection for the tenth-grade honors class is based on 90% achievement in ninth grade science and mathematics; ninth grade entrance examination marks; motivation, as evidenced by requesting the program which involves three extra hours of class time per week; and creativity, judged by teacher recommendations. Selection for the eleventh-grade class is based on the student's ability to identify a specific creative problem in biology, design and carry out controlled experiments on the problem, and draw valid conclusions based upon data gathered.

Fox (Keating, 1976) describes the identification process for junior high students participating in the SMPY. One component specifies a selection procedure for gifted students in a science program. Students are first screened by requiring an overall percentile score of 95 or a percentile score of 98 on the verbal or numerical subtest of the Iowa Tests of Basic Skills or the equivalent. The students are then given the Scholastic Aptitude Test, mathematics and verbal sections (SAT-M and SAT-V). Students receiving a minimum score of 500 and 400 respectively and who are interested in science and score at the seventy-fifth percentile on a tenth-grade norm of a test of general science knowledge should be placed in a special science program, to consist of advanced placement in chemistry, physics, and biology in lieu of general science courses.

Mathematics Programs

Perhaps the most widely publicized mathematics gifted program is the Study of Mathematically Precocious Youth. In 1972 SMPY conducted its first mathematics and science talent search. Initial screening was a ninety-fifth percentile score on a group-administered numerical achievement subtest. In the school districts of Maryland this was usually the Iowa Tests of Basic Skills (ITBS). SMPY testing involved the administration of three tests: (1) SAT-M, (2) Mathematics I Achievement Test, and (3) STEP, Science, Level 1, Forms A and B.

For the second talent search, the screening criterion was boosted to the ninety-eighth percentile on a numerical subtest. The specific testing consisted of the SAT-M and the SAT-V. The Mathematics I test was dropped, since it was felt that the scores did not provide information additional to that provided by the SAT-M. It was also decided that the study would locate exceptional mathematics students and test later for science knowledge. Consequently, the STEP was eliminated. The verbal portion of the SAT was added, since it was found that verbal ability was necessary to participate in the program successfully.

The SMPY identification model in its present form is described by Fox (Keating, 1976). The model consists of three steps: first screening, second screening, and program placement.

The first screening consists of a ninety-fifth percentile overall score or ninety-eighth percentile score on a verbal or numerical subtest, or a combination of both on a standardized achievement test such as the ITBS. An alternative first screening procedure is to nominate students with two or more teacher recommendations who do not fall below the eighty-fifth percentile on overall achievement on a standardized test.

The second screening consists of the administration of the SAT-M and SAT-V or PSAT-M and PSAT-V (Preliminary Scholastic Aptitude Tests). Scores of 500 and 400 respectively on the SAT or 50 and 40 respectively on the PSAT and an interest in science and mathematics are used to select students for program placement.

Howard County (Maryland) Public Schools sponsors a gifted mathematics program for middle school students. The program, (Accelerated Mathematics Program for Gifted and Talented Middle School Students, 1979), is modeled after SMPY. The selection procedure consists of three phases:

1. Students whose overall fifth-grade score is a minimum of the ninety-fifth percentile on the ITBS and whose fifth-grade average scores are 130 on the verbal, non-verbal, and quantitative subtests of the CAT are invited to participate in the second level of screening. Students that do not meet these criteria may be nominated by themselves, their parents, or their school and participate in the second level of screening.

2. Students nominated from the first phase are administered the mathematics and verbal portions of the Cooperative School and College Abilities Test (SCAT), Level II and the Orleans-Hanna Algebra Prognosis Test (OHAPT). Students qualifying for the program are those who receive 215 points or more using the following formula: Two times the SCAT-M, plus the SCAT-V, plus two times the OHAPT. Students receiving 200 to 214 points using this formula may opt for the third level of screening.

3. Students receiving 200 to 214 points are rated by their mathematics teachers in 10 categories, with scores of 1 (low) to 5 (high). Students receiving 45 or more points qualify for the program.

Remarks

A carefully considered student selection method is an important component of any gifted program. In designing the procedure, clear program goals and objectives, a realistic assessment of administrative and fiscal constraints on identification, and well-defined selection criteria will facilitate the efficient and effective selection of students. The procedure should be multidimensional and in addition it is wise to provide avenues for appeal and provisions for reassessment.

Although screening will be similar for science and mathematics programs, identification and selection must be designed for the specific program. This implies that tests, other means for students to demonstrate their proficiency, and recommendations need to be structured so that students' potential for the given program is indicated. However, it may become necessary to compromise the identification instruments and specific criteria desired, for various reasons: time, available resources, budget, the number of students in the pool identified as potentially gifted, and the number of students that can be accommodated.

Instructional Strategies for Teaching the Gifted

Principles of Differentiated Instruction

The goal of any gifted program is to provide qualitatively differentiated instruction. It is through such programming that the educational needs of the gifted are met. However, in an age of fiscal justification and educational accountability it is essential that the components of differentiation be defined. A gifted program should clearly incorporate these components if it is to be defensible. If not, there is a question whether the program is indeed meeting the needs of the gifted.

Simms (1976) defines a differentiated program for the gifted as one that emphasizes the development of higher level cognitive processes. In Bloom's taxonomy these processes are analysis, synthesis, and evaluation. This is not to say that gifted students should not learn the processes of knowledge, comprehension, and application, but since they accomplish these lower levels quickly, they should spend more time with the higher levels.

A second component of differentiation is an emphasis on the processes of thinking as opposed to content learning. Since the gifted are capable of rapid learning, less time need be spent on the teaching of facts and principles. A gifted program should provide opportunities for students to learn how to learn. Process education includes helping students develop abilities in problem solving, research methods, and thinking skills.

As demonstrated by Keating and by Webb, cited earlier, gifted students tend to be formal operational. Consequently, a differentiated program for the gifted should include instructional strategies for strengthening the 14 formal processes described by Sund, also cited earlier.

The notion that these three components of differential instruction are appropriate for the gifted should not be taken to mean that they are not appropriate for other students. Certainly all students should be taught higher cognitive processes, the processes of thinking, and the skills of formal operations. The difference in instructional strategies is based on the different abilities and capabilities of students. Hollingworth (Gold, 1965) states that since the gifted learn in one-quarter to one-half the time needed for average students. instruction that is not appropriately enriched is wasted. All students need to be taught the basics, but the gifted should master them quickly and concentrate on the aspects previously noted. This is true for gifted students at all ages but becomes increasingly salient for secondary students. The mental age of gifted students increases disproportionately with chronological age. Martinson and Lessinger's chart, on the next page, illustrates this principle (Barbe and Renzulli, 1975, p. 234).

MENTAL AGE EQUIVALENTS OF VARIOUS CHRONOLOGICAL AGES AND IQ LEVELS

Actual Chronological Age	Corresponding Grade	M.A. at 130 IQ Level	Corresponding Grade	M.A. at 150 IQ Level	Corresponding Grade	M.A. at 170 IQ Level	Corresponding Grade
6	1	7.8	2	9.0	4	10.2	5
8	3	10.4	5	12.0	7	13.6	8
10	5	13.0	9	15.0	10	17.0	12
12	7	15.6	10	18.0	13	20.4	**
14	9	18.2	13	21.0	**	*	**
16	11	20.8	**	*	**	*	**

* Beyond test level

** Beyond normal school range

The most important consideration in any educational program is to match instruction with the characteristics of the students involved. Students, gifted and others, learn efficiently when teaching strategies match their abilities.

In the section that follows a number of programs and instructional strategies appropriate for the gifted are described.

Gifted Programs and Instructional Strategies

Atamian (1977) describes the Talcott Mountain Science Center (TMSC), which provides a number of programs for the gifted. Students pursue research topics of their own choosing on an individual or small-group basis. The TMSC staff assists students as college faculty would assist graduate students. Students select a topic, develop a plan of attack, and conduct research, using the TMSC's laboratories, libraries, and scientists. As a final product, students are required to write a paper. In general the program is described as following the Enrichment Triad (Renzulli, 1977) discussed in this section. The TSMC staff is composed of full-time employees trained as educators and scientists. Additional specialists are hired and volunteers sought to provide a wide variety of expertise. Advanced students participate as peer teachers for younger students.

The Dade County, Florida, schools (Barr et al., 1978) have a gifted and talented program emphasizing critical thinking, creativity, productive thinking, planning, decision-making, performing and visual arts, independence, evaluation, and leadership. Problem solving is encouraged through stressing individual initiative, self-direction, originality, realistic goal setting, and an attitude of inquiry. It is of particular interest to science and mathematics education that students are involved in the Community Laboratory Research Program. In the program students conduct research in local research facilities: private, government, and university.

Boston (1976) describes meeting the needs of the gifted through the use of mentors. The objective of such a program is to locate "skilled persons in their communities ... to share their interest, commitment, and expertise with youngsters on a one-to-one basis" (p. 1). Boston states that such relationships provide opportunities for learning, experimentation, and skill development. Several implications for education are described:

1. Mentor programs should be experiential, emphasizing observation, perception, problem setting and solving, and practical applications.

2. The mentors and students must be carefully matched, considering the student's interest, motivation, demonstrated ability to learn in individualized settings, ability to get along with adults, and ability to learn from experience; the mentor's willingness to contribute enthusiasm, flexibility, and empathetic qualities; and the student's and mentor's compatibility in learning and teaching styles.

3. The program should be open-ended.

4. The student's progress should be evaluated on the basis of competencies gained rather than curricular territory covered.

Brandwein (1975) proposes that gifted high school students should be independent learners. Curricular strategies for having students realize this goal include student access to information, course work, and additional activities; provisions for learning the art of investigation; and the opportunity to conduct at least two original studies of scientific research. A curriculum based on conceptual themes facilititates the components of independent learning. Furthermore, the means of curricular delivery should not favor the lecture. Laboratory work and original investigations should make up more than half the instructional time.

Keating and Webb, cited earlier, suggest that the gifted tend to be formal operational. Consuegra (1980) describes several instructional strategies for facilitating the progression from transitional to formal operational thought. Four aspects of advanced reasoning are described, and examples for encouraging their development are provided. The key element for developing advanced mental processes is the use of concrete objects and experiences prior to dealing with abstract concepts.

These concrete active experiences are essential to the student's understanding of events and assist the student when exercising newly or partially developed skills.

The 1967 conference of the School Mathematics Study Group provided several recommendations for meeting the needs of the gifted (A Conference on Mathematics for Gifted Students, 1967). Where gifted students are taught within the framework of the regular classroom, supplementary material should be developed. These materials should be open-ended and encourage creative work. For extracurricular work, students should be encouraged to pursue research problems. To supplement these provisions, mathematicians from the academic, government, and private sector should be called upon to provide ass[illegible]nce and guidance. As a curricular culmination, local, regional, and national mathematics competitions should be encouraged.

Anne Crabbe (Crabbe et al., 1978) discusses developing a general program for the gifted. Components that apply to the education of gifted in science and mathematics, she states, are an increased instructional pace providing increased learning, attention span, and in-depth investigation; emphasis on communication skills to facilitate expression of ideas; a curriculum that reflects the student's interests; and a research atmosphere.

In the Research Team Approach to Learning (ReTAL) (DelGiorno, 1977), pilot-tested at the Talcott Mountain Science Center, students investigate a science research topic in groups of three or four. Groups are made up of those assigned the following roles: the researcher describes the problem and makes preliminary literature searches; the investigator defines the problem, states the hypothesis, proposes the experimental design, and interprets the data; the technician performs the investigation; and a recorder coordinates the activities and records the data. The team as a group discusses the topic of study, background information, tests, and results and makes general decisions about the directions of the study. Clearly, ReTAL emphasizes team learning and the use of a variety of means to investigate a problem. The ReTAL learning model consists of four steps:

I. Knowledge

Researcher -- describes the topic or problem and collects background information

Investigator -- states and defines the problem

II. Comprehension

Technician -- determines questions to be answered

Investigator -- forms the hypothesis and designs the experiment

III. <u>Application</u>

Technician -- runs the tests

Recorder -- records the findings

Investigator -- conducts experiments and records the results

<u>Analysis</u>

Team -- discusses the literature, tests, and results

Investigator -- analyzes the data

IV. <u>Synthesis</u>

Recorder -- reports the results to the team

Team -- interprets the findings

Investigator -- draws conclusions from the results

<u>Evaluation</u>

Team -- decides to stop, repeat, or continue study

Investigator -- writes the abstract and determines new directions for further study

The SMPY program for mathematically gifted students (George and Dehan, 1975; George and Dehan in Keating, 1976) advocates fast-paced instruction, resulting in the completion of whole courses of study in a matter of months. Curricular strategies center on the teacher's style: a high degree of openness is stressed, and the teacher is to be receptive to new and different ideas and approaches, taking care not to allow any topic to dominate the discussion. Open-ended questions are posed and investigated, and problems are attacked from several directions by a variety of methods. Students are encouraged to work collectively and independently but are left to master the concepts for themselves. Lectures are characterized by elaborative explanations of the "more elegant tools of algebra" (Keating, 1976, p. 119). To supplement class instruction, extensive homework assignments are made.

Howard County (Maryland) Public Schools, under the funding of an ESEA Title IV-C grant, developed an instructional guide for teaching scientific problem solving. (Instructional Activities and Strategies for Scientific Problem Solving, 1977). The teaching strategies described in the guide encourage divergent and critical thinking skills, the development of creative problem solving -- "e.g., stating problems, stating hypotheses, designing experiments"-- (p. v) -- and critical evaluation skills. The specific steps in the instructional model are as follows.

1. Observation -- a variety of senses and instruments are used to describe the object or phenomenon accurately.

2. Stating a problem -- significant answerable questions and hypotheses are developed.

3. Hypothesizing -- many alternative hypotheses are proposed.

4. Designing an experiment -- selected hypotheses are restated in an "if-then" form, the independent and dependent variables are identified, the experiment is designed and conducted, and data are collected.

5. Analyzing data -- quantitative data resulting from observations and experimentation are analyzed.

As part of the model students are taught brainstorming techniques, the identification of experimental and control variables, and statistical tests.

The Bronx High School of Science (Kopelman et al, 1977) emphasizes a hands-on approach to learning for the gifted. Students progress from speculating, hypothesizing, and designing simple experiments; to recognizing problems, setting up hypotheses, and exploring open-ended problems using the Socratic method; and finally to conducting individual research. Additionally, students complete extensive library research; learn to use scientific journals, papers, and monographs; and interact with research scientists. The product of the final year is a scientifically written report on the student's research.

Renzulli's Enrichment Triad Model consists of three levels of curricular enrichment (Renzulli, 1977). The model is designed to facilitate going beyond the regular curriculum; it is not a means for teaching basic competencies. The model is not curriculum specific and can therefore be d in conjunction with any topic. The first two levels are described as appropriate for all students, and the third level is described as specifically for the gifted. However, gifted students need to go through the two lower levels as they provide the necessary prerequisites for the third level. Each of these three levels are briefly described below.

Type I Enrichment: General Exploratory Activities. This level consists of exposing students to topics of real interest to them. An effort is made to include a wide variety of topics. Such exposure is essential to the student's involvement in Type II and Type III activities. At this level exploration should be purposeful; should be broad, concentrating on epistemological rather than factual aspects; and should provide opportunities for direct involvement with professionals in the field.

Type II Enrichment: Group Training Activities. This level consists of the development of thinking and feeling processes. The emphasis is not content but the operations for dealing with content. However, the content used to develop the processes should reflect student interests.

Type III Enrichment: Individual and Small-Group Investigations of Real Problems. The activities at this level allow the student to become an investigator of real problems. Students engage in inquiry activities typically used to add new knowledge or understanding to a field of study.

Specific guidelines for developing these three levels of enrichment and examples of activities at each level are provided in Renzulli's book.

Verbeke and Verbeke (1972) discusses discovery and inquiry as instructional strategies for teaching the gifted. Justification for such an approach is based on its compatibility with every child's developmental progress as described by Piaget, the need for involving the gifted in problem-solving activities and higher cognitive levels, the objective of making the gifted independent learners, and the recognition that the gifted should learn the processes of thinking. The discovery/inquiry teaching strategy takes place in an open climate where ideas are formulated and tested and divergent points of view are considered. Students are encouraged to discover relationships for themselves, and firsthand investigations are the primary mode of instruction. To facilitate this active involvement, teachers emphasize the importance of well-stated questions rather than the answers to the questions.

Verbeke and Verbeke illustrates the inquiry model by describing Suchman's Inquiry Development Program. The program consists of three stages. In the first stage students verify their observations and gain an understanding of the phenomenon. In the second stage students ask questions to determine the conditions that are relevant to the phenomenon. Additionally, they gather information from a variety of sources and conclude by postulating hypotheses. The final stage involves the testing of a hypothesis.

Remarks

Certain strategies and practices for teaching the gifted are consistently described in the literature. Included are

1. Completing projects and research of personal interest
2. Using trained academic specialists in the field
3. Allowing for open-ended investigations and discussions
4. Emphasizing laboratory work
5. Teaching specific thinking skills
6. Developing library research skills
7. Exploring real-life problems
8. Encouraging higher cognitive skills

These strategies should be developed by teachers to satisfy the overall goals of qualitatively differentiated instruction.

Program Suggestions for Teaching the Gifted

Key Elements of a Gifted Program

Renzulli (Barbe and Renzulli, 1975) reports on a study conducted to identify the essential characteristics of a gifted program. The procedures involved (1) analyzing the literature and other sources to determine a list of characteristics of differentiated education for the gifted, (2) identifying a panel of expert judges in the field of gifted education from persons who had made significant contributions to the field of gifted education, and (3) submitting the list of characteristics identified in the first step to the judges for identification of essential characteristics and a ranking of those items.

The top three features identified were a distinctive curriculum, an appropriate selection procedure, and the selection and training of the teacher. In previous sections of this paper the first two items have been discussed. The following section will address the characteristics of a teacher of the gifted.

Brodbelt (1979), George and Dehan (1975), Goldman (1977), Information Concerning the Program for Gifted and Talented Students, North Carolina (1978), Stanley (Keating, 1976), Verbeke and Verbeke (1972), and Witty et al., (1959) discuss the attributes of a teacher of the gifted. Such a teacher should be knowledgeable and enthusiastic about the subject areas, be warm and empathetic, understand the gifted, and have a good sense of humor. He or she should demonstrate creativity by the acceptance of a variety of approaches and points of view and the willingness to investigate new hypotheses. The teacher of the gifted should be skillful in asking questions that require students to ask further questions of themselves and explore topics in depth. Finally, the teacher of the gifted should have demonstrated ability for working with the gifted, should demand high standards of the students, and should have completed coursework related to gifted and talented education. Without a teacher who meets these criteria it is doubtful that a program for the gifted can be effective and successful.

Program Considerations

Pressey (1955) discusses the nurture of the gifted by comparing the emergence of precocious musicians in Europe in the 1700's and 1800's and of athletes in the United States in the 1950's. His hypothesis is that certain factors facilitate precocity and that educational institutions should promote these factors. Of the five factors identified, four are applicable to educational institutions. Schools should provide the potentially gifted with early and continuing individual guidance and instruction, opportunities for frequent and regular practice of special abilities, occasions for interacting with others with similar abilities and interests, and provisions for real accomplishment in their interest areas. It is speculated that gifted programs incorporating these principles are likely to result in the emergence of an enlarged gifted population.

Gold (1965) outlines several essential components to be considered when developing a program for the gifted. Among those described are the following: The program should be founded on sound educational and psychological bases substantiated by research. It should be consistent with local community attitudes toward and expectations for the gifted. It should be a part of an overall appropriate program for all students. An educational philosophy should be clearly stated, including educational goals and objectives. The program should contain a systematic procedure for identifying participants and an appropriate method for selecting teachers. The curriculum should be appropriate and continuous throughout the grades, with provisions for developing motivation. A program containing these components is likely to be successful for students and defensible to the local community.

It is well accepted that program development for the gifted should differ from that for other students. This difference is often described as not more of the same, but a unique curriculum. Furthermore, the work assigned should not be given in addition to the regular assignments; students should be given the opportunity to learn the necessary basic material quickly and concentrate on the gifted program.

The major issue surrounding the establishment of a gifted program is that of acceleration versus enrichment. Many pundits in gifted education advocate acceleration as an effective and appropriate alternative for a gifted program (Fehr, 1955; Gallagher, 1975; Gold, 1965; Gowan and Demos, 1964; Kough in Shertzer, 1960; Passow in Henry, 1958; Terman in Barbe and Renzulli, 1975; and Ward in Barbe and Renzulli, 1975). However, despite their position and reference to research, teachers and administrators have resisted. Harmful emotional and psychological effects are feared, administrative problems are anticipated, and teachers are apprehensive about the availability of adequate materials.

Perhaps more important than choosing between an accelerated or enriched program is the consideration of the program itself. Simple acceleration of content without provisions for the three components of differentiated instruction will only help the student complete the required educational program sooner. Enrichment that provides broad experiences but fails to challenge the student becomes busy work. A program for the gifted should be one that is challenging and relevant to the student. It follows that such a program for students with exceptional ability must be somewhat advanced if it is to meet their needs. It is perhaps more appropriate to design a program commensurate with the student's individual needs.

Several program suggestions cited in the literature are briefly described below.

Program Suggestions

Fliegler (1961) discusses the secondary science program for the gifted, commenting that the program should be organized so that the gifted student could enter the course sequence at an earlier age than normal. Ninth grade course work would then consist of the biological sciences. Advanced courses in biological science would follow, accompanied by study in the physical sciences.

Abeles (1977) compares a program for average students and an accelerated program for the gifted. He outlines a possible science program for secondary gifted students: grade 7 -- life and/or physical science, grade 8 -- earth science, grade 9 -- biology, grade 10 -- chemistry, grade 11 -- physics, and grade 12-- advanced placement courses such as astronomy, geology, or human physiology.

A study reported in the School Mathematics Study Group conference of 1967 (A Conference on Mathematics for Gifted Students, 1967) concluded that a "contemporary-accelerated" program appeared to be the best alternative for teaching the gifted. Other alternatives studied were "contemporary-enriched," "standard-accelerated," and "standard-enriched." It was noted, however, that such a program did not promote a positive attitude toward mathematics.

In 1972 and 1973, the Hopkins SMPY program (Fox, 1976) called for junior high students to complete Algebra I, II, and III; plane geometry; trigonometry; and analytical geometry by the end of eighth grade. Several students were reported as taking calculus at a senior high school in the ninth grade.

The Accelerated Mathematics Program for Gifted and Talented Middle School Students ("Accelerated Mathematics Program ...," 1979) provides a program consisting of Algebra I and II for gifted students in grade 7. Grade 8 consists of an extensive review of algebra and course work consisting of plane and solid geometry.

Remarks

A program for the gifted is more than content and course sequence. It should be planned so that it is based on a sound educational philosophy, it is consistent with community attitudes and desires, appropriate student selection criteria are followed, and instruction is in the hands of a capable teacher. The program should be balanced between acceleration and enrichment, and the components of differentiated instruction should be part of the instructional strategy. The prime consideration for the program should be meeting the individual needs of the students.

Concluding Remarks

As a group the gifted exhibit characteristics such as high intelligence, advanced thinking skills, excellent memory, high standards for themselves, social maturity for their age, a mature sense of humor, good health, and early physical development. The gifted in science and mathematics exhibit these characteristics as well as a distinct proclivity toward a scientific attitude, relational comprehension, and quantitative understanding.

Identification of the gifted should be multidimensional, consisting of screening, identification, and program planning. Identification of the gifted in science and mathematics should follow these multidimensional guidelines with opportunities for students to demonstrate their potential in science and mathematics. These opportunities might include past performance in science and mathematics and scores on both science and mathematics achievements tests and other tests designed to measure logical processes and quantitative understandings. The characteristics of the gifted in science and mathematics described in this paper might also prove useful in selecting such students for special programming.

Instructional strategies for teaching science and mathematics to the gifted should be qualitatively different from those appropriate for other students. After mastery of the basics, emphasis for the gifted should be on the higher cognitive levels, processes of thinking, and formal operational skills.

A program for the gifted should include accelerated instruction and opportunities for exploring an enriched curriculum. The students' interests and educational needs should be considered when developing an gifted program.

It has been stated that the gifted are our greatest natural resource. Some feel that if we are to overcome current and future world problems, the gifted need to be adequately trained and prepared to provide solutions. However, although this self-preserving point of view may be important, it should not be the prime rationale for providing gifted programs. The gifted, like all students, should be provided with the educational experiences that enable each to fulfill his or her potential. In the case of science and mathematics, gifted programs should provide gifted students the opportunities to explore these topics and provide them with the tools to fulfill their scientific and mathematical destiny.

A P P E N D I X :

Science and Mathematics Materials

for the Gifted

Science and Mathematics Materials for the Gifted

Science

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