The Student Gifted in Mathematics and Science

Julian C. Stanley

Much more needs to be done for the nation's talented students in mathematics and science than is now happening in the schools, asserts this writer, who describes in this article the Study of Mathematically Precocious Youth (SYMPY) at The Johns Hopkins University and what has been accomplished for the young participants.

Mathematics and the sciences are crucially important in today's society. The development of talent in them, however, is often slighted in the educational process. Too few students with great ability in these areas receive sufficient early stimulation with appropriate opportunities to progress at a pace naturally suited to their aptitudes.

Topic Is Vast

Giftedness in mathematics and science is such a vast topic that one cannot hope to cover all its aspects well in a brief article. Fortunately, several comprehensive sources exist. One is "Cognitive and Affective Components of Creativity in Mathematics and the Physical Sciences," a paper presented last fall by William B. Michael of the University of Southern California at the Lewis M. Terman Memorial Symposium on Intellectual Talent at The Johns Hopkins University. It is scheduled to appear in the proceedings of that symposium.

The third volume in *Studies of Intellectual Precocity* will contain a paper by the writer on facilitating the development of mathematical ability and one by Lynn H. Fox on sex differences in mathematical ability. Volumes 1 and 2 of the series are concerned chiefly with mathematically highly talented youths identified initially at ages 12-13, studied considerably, and helped greatly to accelerate with their educational progress.

Julian C. Stanley is professor of psychology at The Johns Hopkins University in Baltimore, Md.

Quantitative vs. Qualitative Science

For insights into the personalities and working habits of great mathematicians, Bell (1937) remains invaluable. As he shows, mathematics itself encompasses a large domain of human intellectual endeavor. Many different types of mathematics exist as do many different approaches to their study. "Pure" mathematicians, who through their penetrating research continually develop the field, are a brilliant but not numerous lot. Most persons who use mathematics apply it to other fields, especially to the mathematical and physical sciences.

Fields that depend greatly on mathematics are mathematical logic, mathematical statistics, physics, physical chemistry, electrical engineering, mathematical genetics, computer science, operations research, mathematical psychology, quantitative economics, and quantitative sociology. Others that also use it, but less, are the history and philosophy of science, organic chemistry, biology, botany, and medicine.

As one goes along this approximate quasi-continuum from mathematics itself to medicine the importance of excellent mathematical reasoning ability for entering the field diminishes, but even for applicants to medical school some background in calculus is usually required.

Increasingly, however, most of these fields are being mathematized, so that by the time most of today's students are in mid-career a non-quantitative home within science will be difficult to find. The youth who does not have a fairly good grasp of calculus by the time he *enters* college may already be handicapped for starting a scientific career.

For example, an intellectually gifted premedical student in our Study of Mathematically Precocious Youth (SMPY) entered a college's beginning calculus class without having studied any calculus in high school and was so overwhelmed by the competition from others with more background that she made a grade of "C" the first semester. Frustration over this class also adversely affected her other grades and severely hurt her chances of continuing in the premedical curriculum.

Identifying Students Gifted in Math, Science

Some students are so precocious that they stand out startlingly for all to see. The youthful Gauss was not long in convincing his primary school teacher and classmates that he had rare mathematical ability indeed. The young Einstein, Newton, Mendel, and Darwin were not as fortunate. Even at the potential genius level, careful early study is required to avoid the problem that Thomas Gray lamented:

> Full many a gem of purest ray serene
> The dark unfathomed caves of ocean bear;
> Full many a flower is born to blush unseen,
> And waste its sweetness on the desert air.

How much more important it is to delve diligently into the great reservoir of talent that lies below the potential genius level. As many have shown, unaided teacher judgment is not a sufficient locator of great talent, nor are in-grade tests even though both can provide leads to follow. Students considered by teachers to be mathematically talented and those who score high on mathematical sections of the tests usually given in their grade can be studied further with more difficult tests.

SMPY's first mathematics and science talent search, conducted in March of 1972, illustrates a powerful method for determining which 12- and 13-year-olds excel nearly all of their agemates in mathematical reasoning ability and/or knowledge of general science. Students who had scored in the top five percent for their grade on national norms in mathematics (for whichever standardized achievement test battery their school used) were invited to enter a contest, competing in mathematics only, in science only, or in both.

The mathematics reasoning test used in the contest (but preceded by practice materials) was the 60-item, 75-minute multiple-choice mathematics part of the College Entrance Examination Board's Scholastic *Aptitude* Test (SAT-M). Designed for use with above-average eleventh and twelfth graders, it employs quite elementary mathematical content for testing the student's ability to reason fast and well.

Most seventh or eighth graders have had so little systematic exposure to mathematics beyond arithmetic that the SAT-M forces them to work at the analysis level of Bloom's (1956) taxonomy of educational objectives; the well-schooled eleventh or twelfth grader can solve many of the SAT-M items at lower levels of mental effort, chiefly application. To answer the majority of the 60 items correctly the junior high youth must have powerful reasoning ability, great flexibility of thinking, and a robust ego not to be overcome by the test's difficulty.

Results were splendid. Even the seventh graders who entered the contest averaged higher on SAT-M than did a random sample of male high school seniors. Ten percent of the boys scored better (i.e., at least 660) than the average Johns Hopkins University freshman had done as an eleventh or twelfth grader. The talent search turned up much superior talent that had been recognized only incompletely or overlooked.

For the science part of the contest both forms of the highest level of the Educational Testing Service's Sequential Tests of Educational Progress (STEP) science test were used—75 multiple-choice items per form and a one-hour time limit for each form. The average student scored high on his college-level measure of knowledge of many areas of science. The top scorer was a 12-year-old seventh grader, who also ranked high on SAT-M. His 137 out of the possible 150 science points exceeded the scores of 99 percent of college students in the national norm population who were tested in the spring of their sophomore year.

The principle we used was simple: administer to the upper few percent of the age group a test difficult enough to reveal their abilities relative to each other and to older students. For example, the 99th percentile (i.e., the upper one percent) extends all the way to plus infinity. Students labeled as "99th percentile by an in-grade test may vary greatly in ability, from the 99.0th percentile to the 99.99th or higher. Being one in 100 denotes far less talent than being one in 500 or 1,000 or 10,000. Teachers cannot be expected to make distinctions even within the top five or 10 percent without the assistance of appropriate tests.

Also, students who score high on an in-grade mathematics or science test because they are excellent at rote-learning aspects of the subject (e.g., mathematical computation) may not look nearly as able when confronted with a difficult reasoning test.

Studying the Talented Further

Terman (see Oden 1968), Hollingworth (1942), and many others have provided excellent descriptions of intellectually gifted children. Few have studied their other cognitive characteristics, however. The three-pronged aim of SMPY was to find mathematically precocious youths, study them intensively and extensively, and help them educationally. The upper seven percent or so each year were invited to return for an additional full day or two of testing, plus completing questionnaires, interviewing, and counseling. They were administered difficult tests of mathematics and science knowledge, nonverbal reasoning, mechanical comprehension, spatial relationships, synonym-antonym knowledge, verbal analogical reasoning, interests, evaluative attitudes, and personality.

Our goal was to understand the student well enough to help him find suitable educational avenues to maximum use of intrinsic talent. Among other things, this meant separating the generally bright, but not mathematically or scientifically highly promising students, from the ones whose best prospects were in direct utilization of great mathematical reasoning ability.

For instance, our highest SAT-Verbal plus SAT-M scorer in 1973 (710 + 770 = 1840 at barely age 13) could hardly do even the sample items for the mechanical comprehension test. He was not outstanding in the top group with regard to his knowledge of mathematics or science, nor was he a superb nonverbal reasoner. Inquiry revealed that his chief interests were political science and law, but on the questionnaire his first choice had been aeronautical engineering—a field in which, despite his extremely high IQ, he would likely not be excellent or well satisfied.

We set out in SMPY to devise an array of educational possibilities from which the splendid mathematical reasoners could choose *a la carte*, taking whatever they were *eager* to pursue: one thing or another, many different things, a few things, or nothing. We had narrowed down to mathematical reasoning because that type of ability can develop to a high level early and depends less on personal experience than most other school areas do. For a seventh or eighth grader, mathematics and related subjects such as computer science can be viewed as a game, a closed deductive system that one can enjoy without having had to live long and suffer the vicissitudes that might add to one's appreciation of poetry, literature, or philosophy.

We also chose mathematical ability because mathematics as taught in the secondary school and the first two years of college is more hierarchical than other areas tend to be. A mathematically highly apt student can complete a lower phase of it fast and go on to the next stage—for example, do first-year algebra in a few hours and enter second-year algebra. For most superior mathematical reasoners it is boring and stultifying to spend 180 45- or 50-minute periods in Algebra I, when they could readily complete both Algebra I and II—and perhaps much more—during the school year.

We chose accelerative procedures in preference to that glamorously titled procedure, "enrichment," because the latter, as usually practiced, merely increases the boredom now or puts it off for a little while but makes it worse then (see Stanley 1976b).

Our smörgåsbord consisted of special fast-math classes (Fox 1974b and 1976b; George and Denham, 1976; and Stanley 1976d), taking college courses for credit on a part-time basis (Solano and George 1975), skipping grades, entering college as full-time students without completing high school (George and Stanley 1975), skipping mathematics courses learned quickly on one's own, credit by examination, correspondence study at high school or college levels, and the like. SMPY's rationale for planning accelerative programs is set forth by Fox (1974a and 1976a) and Stanley (1975).

Who Knows What's Best?

It seems important to reemphasize that the prime consideration in counseling highly able students about the above choices was the youth's own personal eagerness to try a given way to speed up his progress in mathematics and school. The combination of intellectual and motivational readiness produced many remarkable successes while minimizing academic and personal difficulties. We learned that most brilliant students know what is best for them at a given time better than we do, if we and their parents and teachers will sit back and let them do some thinking without harassment.

In short, SMPY thus has succeeded better than we had dared hope when the study began in the fall of 1971 with funding by the Spencer Foundation. More than 200 excellent mathematical reasoners have used their opportunities to good advantage. Some have done just one thing once, whereas others have tried many different things repeatedly. A boy entered college full time at age 11-1/2 after completing only the sixth grade of a public school. He started with Calculus III and made an A in it. At age 13 he completed the fifth semester of college with nearly all As.

In the fall of 1975 there was a 15-year-old junior at Johns Hopkins, three 16-year-old juniors, and a 17-year-old junior. A student entered at age 13 after the eighth grade of a public school and completed his master's degree in computer science at age 17 years, 10 months. At present Johns Hopkins has a total of 15 students who entered one to five years early under SMPY's auspices. Thus far at Johns Hopkins and elsewhere there have been 44 early entrants, even though the unaccelerated eighth graders from our first talent search are only high school seniors during the current school year!

Most of the accelerants are majoring in some branch of science, rather than in mathematics itself. Electrical engineering is popular, as are computer science and physics. We were surprised to find political science rather popular but chemistry and biology not chosen as majors. Few of the males and a large percentage of the females seem headed for medical school.

In the 1972 contest we chose nine mathematics "winners" and seven science winners; with overlap (three won in both areas) there were 13 winners. What has happened to them? All three double winners entered Johns Hopkins as full-time students at very early ages, one at age 14 and the other two at age 15 with sophomore standing. Six of the eight math-only winners—and perhaps a seventh—entered college early. Two of the four science-only winners went early.

After the first year we discontinued the science talent search because few of the science winners were poor in mathematics and, especially, because we decided that excellent mathematical reasoning ability was necessary for success in most sciences and should therefore be ascertained first. The SAT-M scores of the four science-only winners were 680, 670, 600, and 550, whereas the average male high school senior scores not much over 400.

An Illustrative Case Study

The progress of a boy with whom SMPY has been associated since September of 1971 and whose file folder is now an inch and a half thick will show how a highly able, exceptionally well motivated student can use most of the accelerative possibilities to break completely loose from the snail's pace he endured through the sixth grade.

The boy was born December 4, 1959, so he was still 11 years old and retarded a year in grade placement when the Maryland Academy of Sciences called him to our attention because of his performance in one of its computer courses for elementary school students. Having moved into the Baltimore area after starting school elsewhere, he was one of the oldest students in his sixth grade, and probably the ablest both verbally and mathematically. But being only a sixth grader, he did not yet know nearly enough mathematics to match his great arithmetic reasoning ability. (By age 13-1/6 he scored 610 on SAT-V and 750 on SAT-M.)

What did we help him do? First, he arranged to skip the seventh grade the next fall and thereby become one of the youngest students in the grade rather than the oldest. Then, in June of 1972 he became one of the students in SMPY's first fast-math class; by August of 1973 in 60 two-hour weekly sessions he had completed at a high level the equivalent of two and one-half years of high school algebra, a year of plane geometry, and a year of trigonometry and analytic geometry. During that year he did not take any mathematics in school.

In the fall of 1973 he skipped the ninth and tenth grades and became an eleventh grader in a large public high school. There he took calculus, chemistry, and other subjects and studied physics on his own. In May of 1974 he scored well on the Advanced Placement Program national examination in calculus and in physics, earning a total of 14 credits for them at Johns Hopkins.

Meanwhile, "on the side" he had been taking college courses for credit. The first was computer science in the regular day session of Johns Hopkins when he was a 13-year-old eighth grader; his final grade was A. He also made A or B in economics, fundamentals of mathematics, political science, and a year of chemistry lecture and laboratory. With his advanced placement credits and these college courses he entered Johns Hopkins in the fall of 1974 with 34 semester hour credits of advanced standing, thereby being a sophomore at age 14 3/4. The first semester he made As on advanced calculus and number theory and Bs on sophomore physics and government. He has now completed the first semester of his junior year with good grades.

At this point the reader may be anxious to know about his social and emotional development. How can a boy who takes only one year in junior high school, one year in senior high school, and three years (or less) in college possibly have any fun?

During his year in senior high school he won a letter in wrestling, served as the math-science whiz on his school's TV academic-games team, played golf well, tutored a boy only a year and a half younger than he but four grades lower in school through three and one-half years of mathematics, helped his 14-year-old friend get elected president of the student council, and had time for many other activities.

To him it was exceedingly important to move ahead rapidly into more appropriately difficult and interesting material. He had not complained much about boredom in the lower grades, but once the opportunities became available he seized them.

Like most brilliant youths, the student we are describing is not narrowly bookish or a "greasy grind." His interests are broad, ranging from physics and computer science to political science and management. He is intelligently planning a career that may culminate in his managing or directing a major scientific enterprise. Being only 16 years old, however, he is keeping various avenues open: work experience after receiving the B.A. degree, perhaps combined with studying part-time for a master's degree and then going on full time for a Ph.D. degree and/or an M.B.A. degree from a major business school. If SMPY had not found him four and one-half years ago, he would probably be in the tenth grade this year (rather than the fifteenth) and almost surely far less likely to make a splendid future for himself and society.

The boy is exceptionally able, of course, but by no means the brightest person we have located through SMPY's talent searches. For example, a 13-year-old scored 740 on SAT-V, and a 12-year-old scored 800 on SAT-M. As noted above, a 13-year-old scored 710 on V and 770 on M. His motivation, efficiency, and effectiveness are, however, near the top of the group.

Conclusion

Excellent ways exist to identify students at a rather early age, at least by the end of elementary school, who have special talent for mathematics and science. They can then be studied further to ascertain other abilities they have and how the interests, values, attitudes, and other personality characteristics of the youths should be taken into account in nurturing their academic and personal development.

Vastly more needs to be done for such students, however, than is now being done in most school systems. The Study of Mathematically Precocious Youth at The Johns Hopkins University has tried a number of ways to help students who reason especially well mathematically break the typical age-in-grade lockstep. These are set forth in two books and several articles.

Fortunately, providing adequately for the mathematically and scientifically highly talented is not expensive. This facilitation requires commitment by some school personnel, ingenuity, and persistence, but in the long run it is likely to save schools and parents considerable money.

As I said elsewhere (Stanley 1974, p. 19):

> It seems uncomfortably probable that much of the intellectual alienation of brilliant high-school graduates is due to their having been educated at a snail's pace too many years. It is time for . . . schools to do feasible, sensible things to prevent this atrophy of intellectual motivation.

Mathematics and science are good subjects with which to start sustained efforts to help the talented move along as they should, using just the right amount of encouragement to strive. Paraphrasing Robert Browning, "A mathematically precocious youth's reach should exceed his grasp, or what's an educational system for?" Surely we can extend both the reach and the grasp of our brilliant youths!

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