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Scope of Study: The primary purpose of this study was to determine why Archimedes, Newton, and Gauss are considered the greatest mathematicians of all time. A secondary purpose was to evaluate the possibility that some twentieth century mathematician will in time be considered as great as these. Library research was used to obtain information about the lives and mathematical contributions of these three men and the relative development of mathematics in this century. The study is written in narrative style. Facts about the personal lives of these men have been included for coherency.

Findings and Conclusions: Without exception, the writer of mathematical history group Archimedes, Newton, and Gauss together as the three greatest mathematicians of all time. It was interesting to note the hesitancy of these writers to range these three in order of merit. None of the three had a contemporary that approached them in greatness. The contributions made by each to mathematics, both creative and developmental were spectacular and had a profound effect upon succeeding developments in both mathematics and other branches of science. Each understood the complete field of mathematics as it existed in his time. The explosive development and high degree of specialization of mathematics in the twentieth century makes it unlikely, only possible, that there will be a successor to the three giants.

ADVISER'S APPROVAL James H. Zant

MATHEMATICAL GIANTS: ARCHIMEDES, NEWTON, GAUSS AND A POSSIBLE TWENTIETH CENTURY MATHEMATICIAN

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PREFACE

Why are Archimedes, Newton, and Gauss considered the greatest mathematicians of all time? The primary purpose of this report is to examine the lives and mathematical achievements of each of these men in order that one can understand why they are so highly rated. The contributions made to mathematics by Archimedes, Newton, and Gauss, both creative and developmental were spectacular and had a profound effect upon succeeding developments in both mathematics and other branches of science.

I wish to thank Dr. James H. Zant for his assistance in the writing of this report. Thanks are also due him and the National Science Foundation for making an academic year and a summer of study possible.

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CHAPTER I

INTRODUCTION

Superlatives of one type or another hold a certain degree of attraction for everyone. How high is the tallest mountain? Who has hit the greatest number of home runs in the history of baseball? What is the greatest speed attained by a piloted aircraft? The answers to questions relative to primacy are usually interesting. Who was the first president of the United States? What group of people first inhabited Greenland? What country will first land a living man on the moon?

The purpose of this report has no relation whatsoever with the answers to these questions. However, the idea of superlatives and primacy is an integral part. Who is the greatest mathematician of all time? The writer hoped a unique answer to this question had been given unanimously by the authors of mathematical history books and could readily be found by reading the literature. Such was not the case.

The following quotation is representative of the best answer found:

> Archimedes, Newton, and Gauss, these three, are in a class by themselves among the great mathematicians, and it is not for ordinary mortals to attempt to range them in order of merit. All three started tidal waves in both pure and applied mathematics: Archimedes esteemed his pure mathematics more highly than its applications; Newton appears to have found the chief justification for his mathematical inventions in the scientific uses to which he put them, while Gauss declared that it was all one to him whether he worked on the pure or the applied side, nevertheless Gauss crowned the higher arithmetic, in his day the least practical of mathematical studies, the Queen of all.[1]

In other books, reference to which will be made in the following chapters, the writer found this trio of mental giants referred to collectively as the greatest mathematicians of all time. Why? What is there about these three that causes them to be considered as an exclusive group?

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[1] E. T. Bell, <u>Men of Mathematics</u> (New York, 1937), p. 218.

The basic purpose of this report is to answer this question. In doing this secondary questions arose that needed answering to make the report more coherent and interesting. One would expect the main prerequisite to greatness would depend on the contributions made. The contributions made to mathematics by Archimedes, Newton, and Gauss, both creative and developmental were spectacular and had a profound effect upon succeeding developments in both mathematics and other branches of science. These contributions and their significance are discussed in some detail in later chapters. Narrative style is used since it is not the purpose of the writer to delve into the mathematical intricacies of these achievements. What is the role of mathematics in society? The answer would depend on the person answering.

Great mathematicians have played an integral part in the development of scientific thought but few mathematicians, if any, would agree that the only purpose of mathematics is to serve science. Archimedes believed that this was not a purpose at all. Bell (1937) stated it this way:

> It must not be imagined that the sole function of mathematics is to serve science. Mathematics has a light and wisdom of its own, above any possible application to science and it will richly reward any intelligent person to catch a glimpse of what mathematics means to itself, not art for art's sake but art for humanity's sake. So we shall attend also to some of the things which the great mathematicians have considered worthy of understanding for their own intrinsic beauty.[2]

So the sometimes opposite ideas of intrinsic and extrinsic worth of mathematics influenced the direction of achievement of the three men about which this report is written.

Very seldom is a mathematical concept created entirely by one person. A new idea may be in the process of maturity for several generations and involve a number of mathematicians. Then someone perfects it. The mathematician who perfects an idea many times receives more than his due share of credit to the semi-exclusion of the person who nurtured the idea in the rudimentary stage. A good example of this are the methods of the integral and differential calculus. Archimedes had some fundamental notions, for example the idea of limiting sums, and knew how to apply them. In the seventeenth century Newton and Leibniz perfected these concepts and are

[2] Ibid., p. 4.

generally given credit for their invention.

From the earliest times two opposing tendencies, sometimes helping one another, have governed the whole involved development of mathematics. These are the ideas of discreteness and continuity. The discrete has as its domain algebra, the theory of numbers, and symbolic logic. The conception of continuity, "no nextness" leads into the boundless domain of the calculus or more generally, mathematical analysis. Geometry employs both the continuous and the discrete.[3] Great mathematicians have achieved equally well in each area. Archimedes worked with both aspects, geometrical concepts of measure receiving much attention. Newton's need for the concept of continuity was so essential in his formulation of the universal law of gravitation that he invented the calculus. Gauss worked largely in the field of theory of numbers.

What is a professional mathematician like? The scientist is characterized more often in fiction and on the screen than is the mathematician. Quite often each is pictured as an idealistic dreamer without common sense. Only by seeing in detail what manner of men some of the great mathematicians were and what kind of lives they lived can one get a true picture of them. The lives they follow, their motivations, and ambitions will at least suggest that a mathematician can be as human as anybody else. As a group they have been men of all-around ability, vigorous, alert, and interested in many things outside of mathematics.

Are mathematicians unusally tempermental? Some have become embroiled in controversy but in many cases it has been a matter of defending a principle. Newton became entangled with Leibniz over priority of invention of the calculus but most of the envy was at the national level. The inclination of Gauss not to publicize his works caused many other mathematicians to lay claim to ideas that he had developed earlier. However, Gauss seemed to prefer to remain aloof from public controversy. Over the spans of time historical perspective causes the importance of priority to wane and the mathematical concept itself becomes significant, provided it is a link in the main stream of mathematical development.[4]

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[3] Bell, The Development of Mathematics (New York, 1945), pp. 13-14.
[4] Bell, Men of Mathematics (New York, 1937), pp. 8-10.

Even Archimedes, Newton, and Gauss, with supreme powers of concentration for their work were not immune to the effect of their personal and general surroundings. Consequently personal and national events had a direct bearing on their lives and accomplishments. For this reason and to give the narrative a personal touch, the writer has interspersed in the succeeding parts of this treatise personal and social events that affected the lives of thse mental giants.

Speculation exists in various and sundry forms since it has a fascinating appeal for many people. Occasionally there is speculation of a sort on what accomplishments certain mathematicians might have made had they lived in another age or had the cultural atmosphere been different. This seems to be an interesting indulgence of the imagination but in many respects is idle and useless. The historical facts are either they did or did not.[5]

The writer feels inclined to be idle at this point by posing some speculatory questions: what else might Newton have accomplished had he not worked the last thirty years of his life at a relatively menial task? The same might be asked about the twenty years Gauss used computing the orbits of minor planets. Archimedes mathematized until he was killed at seventy-five. Would any one or all of the three, should he be living today, be able to understand the complete field of mathematics as it is now developed?

Now for the last question: has or will the twentieth century produce another mathematician, X, equal in stature to Archimedes, Newton, or Gauss? The writer does not propose to answer these questions but the last one is discussed in some detail in the concluding section.

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[5] Bell, Development of Mathematics (New York, 1945), p. 145.

CHAPTER II

ARCHIMEDES

Archimedes was born about 287 B.C. and died in 212 B.C. There seems to be some uncertainty about the exact date of his birth but the particulars of his death are reasonably well known, varying only in detail. He was killed by a Roman soldier during the invasion of Syracuse, Sicily.

Although today Archimedes is usually remembered for his mechanical inventions and his work in connection with mechanics and hydrostatics, his greatest work, by far, lay in the field of pure mathematics. As a mathematician, he was supreme and unchallenged. Regardless of how he is viewed, one cannot fail to be amazed by the remarkable range of subjects and the mastery of treatment. He is the one who succeeded in: performing what are really integrations for the purpose of finding the area of a parabolic segment and a spiral, the surface and volume of a sphere and a segment of a sphere, and the volume of any segments of the solids of revolution of the second degree; finding the center of gravity of a parabolic segment, calculating arithmetical approximations to the value of pi, inventing a system for expressing in words any number up to that of a one followed by 80,000 billion zeros, and inventing the whole science of hydrostatics.[1]

Bell has this to say about Archimedes:

> Archimedes, the greatest intellect of antiquity is modern to the core. He and Newton would have understood one another perfectly, and it is just possible that Archimedes, could he come to life long enough to take a post-graduate course in mathematics and physics, would understand Einstein, Bohr, and dirac better than they understand themselves. Of all the ancients Archimedes is the only one who habitually thought with an unfettered freedom, for he alone of all the Greeks had sufficient stature and strength to stride clear over the obstacles thrown in the path of mathematical progress by frightened geometers who had listened to the philosophers.
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> Any list of the three greatest mathematicians of all

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[1]T. L. Heath, The Works of Archimedes (New York, 1897), pp. 5-6.

history would include the name of Archimedes. The other two usually associated with him are Newton (1642-1727) and Gauss (1777-1855). Some, considering the relative wealth, or poverty, of mathematics and physical science in the respective ages in which these men lived, and estimating their achievements against the background of their times, would put Archimedes first. Had the Greek mathematicians followed Archimedes rather than Euclid, Plato, and Aristotle, they might easily have anticipated the age of modern mathematics by two thousand years.[2]

One wonders how Archimedes did all this. He had an extremely high power of concentration and when he was engrossed in the study of a problem, nothing could detract his attention from it, not even the necessities of life. He used anything and everything that would be helpful in the attack on the problem. This is one of the reasons, his method of attack, he is given credit for having a "modern" mind. As an example he used his mechanics to advance his mathematics. Newton did the same later. Praise is due Archimedes for breaking out of the philosophical straight jacket of Plato whose conception of respectable geometry made taboo the use of instruments in geometric construction other than the straightedge and compass. All his extant works are characterized by precision and rigor such as is not found in any of his predecessors with the possible exception of Euclid. His works are monuments of mathematical exposition. The gradual revelation of the plan of attack, the ordering of the propositions, the elimination of the irrelevant, and the finish of the whole are so impressive as to create a feeling of awe for such intellect.[3]

It is difficult to explain in a concise form the works of Archimedes since he wrote on nearly all the mathematical subjects then known and the reason for which these were written. Unlike Euclid who aimed at producing systemic treatises which could be understood by nearly all students, Archimedes wrote brilliant monographs for the reading of the most educated mathematicians of his time.

In plane geometry, the known writings of Archimedes deal with the measurements of a circle, the quadrature of the parabola, and one on spirals. In the measurements of a circle, one of the propositions he proved geometrically was a method for finding the ratio of the circumference of a circle to its diameter, pi, to be between $3\frac{1}{7}$ and $3\frac{10}{71}$.

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[2]Bell, Men of Mathematics (New York, 1937), pp. 19-20.

[3]Heath, The Works of Archimedes (New York, 1897), pp. 6-7.

This was a remarkable achievement considering the kind of mathematical tools at his disposal. In some respects his work on spirals is the most remarkable of all his contributions to mathematics. Many writers see in his method of drawing a tangent to his spiral an anticipation of the method of the differential calculus.

The works of Archimedes in three dimensional geometry include one on the sphere and the cylinder and one on coniods and spheroids. The work on the sphere and the cylinder contains sixty propositions and makes up two books. In the second book a cubic equation occurs. With one exception, no such equation appears again in the history of European mathematics for more than a thousand years.[4] It is a lengthy piece of work. In it he finds expressions for the surface and volume of a pyramid, of a cone, and of a sphere, as well as of the figures produced by the revolution of polygons inscribed in a circle about a diameter of a circle. Archimedes is said to have requested that a representation of a cylinder circumscribing a sphere within it be placed upon his tomb together with an inscription giving the ratio which the cylinder bears to the sphere. From this one may infer that he regarded the discovery of this ratio, or the work that contained it, to be his greatest achievement.

Archimedes wrote two papers on arithmetic. One, which is now lost, was on the principles of numeration. The other was called the <u>Sand-reckoner</u>. In the <u>Sand-reckoner</u> Archimedes devised a system of representing large numbers beyond the range of the current Greek system of numeration. He showed that it was possible to assign a number to the number of grains of sand which would fill the whole universe, that is a sphere whose center is the earth and radius the distance to the sun.

In body and mind Archimedes was an aristocrat. He was the son of Pheidias the astronomer and was on intimate terms with Hieron II, King of Syracuse, Sicily and his son Gelon. This relationship with the king has been the background for several stories regarding the uses made of his mechanical inventions based on his extensive knowledge of the principles of mechanics and hydrostatics. Although he was one of the greatest mechanical geniuses of all time, if not the greatest when one considers how little he had to go on, the aristocratic Archimedes had a sincere

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[4]W. W. Rouse Ball, <u>A Short Account of the History of Mathematics</u> (London, 1922), pp. 67-71.

contempt for his own practical inventions. These things were merely the "diversions of geometry at play" and he attached no importance to them. It seems he regarded as ignoble and sordid the business of mechanics and every sort of art which is directed to use and profit. At various times, however, Hieron prevailed upon Archimedes to put to practical use some of his inventions. Some of these were used to advantage during the siege of Syracuse by the Romans. An example was the catapult used as a missile thrower.

The story goes that Archimedes died, as he had lived, in mathematical contemplation. Numerous accounts, which differ in detail, have been given regarding the circumstances of his death. The essence of the story is that during the confusion that followed the capture of Syracuse, Archimedes was studying some figures he had drawn on the ground and was killed by a Roman soldier who did not know who he was.[5]

Thus perished the greatest mathematician of antiquity, possibly the greatest of all time. With the death of Archimedes, the Golden Age of Greek Mathematics comes to an abrupt end. Not for eighteen centuries was the mathematical torch lighted by Archimedes to be rekindled almost simultaneously in England and Germany.

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[5]Heath, The Works of Archimedes (New York, 1897), pp. 15-22

CHAPTER III

NEWTON

Isaac Newton was born in 1642, the year of Galileo's death, in the hamlet of Woolsthorpe near Grantham, England. He died at Kensington, London in 1727 and is buried in Westminster Abbey. During these eighty-five years, the contributions he made to mathematics and science are unsurpassed in the history of man. Toward the close of his life, Newton gave the following estimate of himself:

> I do not know what I may appear to the world; but to myself I seem to have been only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.[1]

Speaking again in a modest vein the following is attributed to him: "If I have seen a little farther than others, it is because I have stood on the shoulders of giants"[2]

His successors capable of appreciating his work almost without exception have pointed to Newton as the supreme intellect that the human race has produced. Newton is almost unique in his triple supremacy as a pure mathematician, an applier of mathematics, and an experimentalist. Of the other two usually assigned to his class, Archimedes is generally considered his equal, and Gauss his superior in pure mathematics but his inferior in other respects.[3]

Newton's life can be divided into three distinct parts: the first, his youth in Lincolnshire; the second, his life at Cambridge; the third, his work at the Mint.

Not enough is known about Newton's ancestry to interest students of heredity. His parents were small, independent farmers. Newton's father

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[1] Sir David Brewster, The Life of Sir Isaac Newton (London, 1875), p. 303.

[2] Ibid.

[3] Bell, The Development of Mathematics (New York, 1945), p. 148.

died before his son was born. Frail at birth and not robust as a child, Newton was forced to shun the rough games of boys his own age. After her husband's death, Mrs. Newton married again and had three children by this second marriage, none of which exhibited any remarkable ability. From his father's estate and property arrangements of this second marriage came enough income so that Newton was not one of the great mathematicians who had to contend with poverty.

Instead of amusing himself in the usual way, Newton invented his own diversions, in which his genius first became apparent. It is cometimes said that Newton was not precocious. If this is true with respect to mathematics, it is not true in other respects. The unsurpassed experimental genius which Newton was to exhibit later in the exploration of light is evident in the ingenuity of his childhood inventions. Some were kites with lanterns, perfectly constructed mechanical toys, waterwheels, and a flour mill with power furnished by a mouse.

A maternal uncle seems to have been the first to recognize that Newton was something unusual. He persuaded Newton's mother to send Isaac to Cambridge instead of keeping him at home, as she had planned, to help her manage the farm. Newton was not interested in farming. Once during a biolent wind storm, instead of being concerned about the welfare of the cattle and buildings, he spent his time jumping with the wind, then against it in an attempt to estimate the force of the wind.[4]

The joy of creating mechanical objects in early life turned later to the creation of intellectural concepts. His interests were overwhelmingly intellectual; he never married; he was unmindful of the way he dressed; his meals would go untouched when he was working on a problem. Fortunately, he became physically stronger than when a boy and managed to stand the strain of working as long as eighteen hours on end. Like Archimedes he possessed the power of concentration to a remarkable degree. His mind would close on a problem and nothing was allowed to divert his attention from the solution. Various stories have been told about his oblivion to everyday things. The one that follows is particularly amusing to the writer. "On one occasion, it is said, while leading his horse up a steep hill, he turned his mind to some problem. Some considerable time later he

[4] S. Brodetsky, Sir Isaac Newton (Boston, 1928), pp. 5-10.

was puzzled to find the bridle still in his hand but no horse attached to it."[5]

At the beginning of his career, Newton discovered that mathematicians and scientists were apt to question and criticize new methods and theories. At first he answered and explained his work but later became impatient with wasting time replying to his critics and became reluctant to make public his latest findings. He made a statment to the effect that a man must not make public anything new or he would be forced to become a slave defending it. Gauss felt the same way in connection with his work on non-Euclidean geometry.

Two of the better known disputes in which Newton became engaged was the one with Hooke over the basic nature of light and the one with Leibniz over the invention of the calculus. The latter might have been avoided had Newton made public immediately his use of the calculus. From a mathematical standpoint, in quantum theory features of both the corpuscular and wave theory of light are compatible. Regarding the invention of the calculus, the concensus of opinion at present is that both Newton and Leibniz invented it independently.

It was during the period at Cambridge that Newton discovered and invented his major contributions to mathematics and science, even though some of his findings were not made public until later. Newton's major works include: his study of light and optics; his invention of the calculus; and his formulation of the universal law of gravitation. No attempt is made to outline in detail the preliminary studies and conclusions made by Newton or a complete exposition of the final results. This would be so extensive that it would entail volumes rather than pages. Newton's interests were essentially and primarily that of an experimenter. But experimental thinking whose scope in the universe calls for mathematical calculations. Some of the problems involved concepts unknown. Newton invented the mathematics needed.

The Great Plague (bubonic plague) caused the closing of Cambridge for two years and Newton retired to Woolsthorpe. Up until this time, 1664, he had done nothing remarkable, or if he had, it was a secret. In these two years the flood gate of mental achievement was opened. During this time

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[5]Alfred Hooper, <u>Makers of Mathematics</u> (New York, 1948), pp. 276-278.

he invented the calculus, discovered the law of universal gravitation, and proved experimentally that white light is composed of light of all colors. Newton was not yet twenty-five.[6]

Newton made with his own hands the first reflecting telescope. He also worked on the refracting type. The discovery of the spectrum was an extremely important event in the history of science. By using it correctly, one can discover the constitution of the stars, determine whether the motion is toward or away from us, evaluate the events on the sun's surface which reveal electro-magnetic fields and disturbances. The spectrum has been used to give an insight into the ultimate constitution of matter, and has led to the formulation of the quantum theory and helped to establish Einstein's gravitational theory. As has been indirectly stated earlier, Newton formulated the corpuscular theory of light; the idea that light is composed of tiny corpuscles, or particles, that are projected through space by luminous bodies.

The _Principia_ or _Mathematical Principles of Natural Philosophy_ is Newton's masterpiece. Many superlatives have been used to describe it. One statement is that it is still rated as the most massive addition to scientific thought ever made by one man. It was arranged in three books: the first book laid down the principles of dynamics; the second, the motion of bodies in resisting media, and fluid motion; the third was the famous "System of the World". Probably no other law of nature has so simply unified any such mass of natural phenomena as has Newton's law of universal gravitation. The _Principia_ is not a reproduction of the learning of the past with original touches. The fundamental laws of mechanics are formulated for the first time, the mathematics required in the arguments are invented by Newton himself, the phenomena explained had never been satisfactorily accounted for before, the problems initiated have since occupied the best minds of humanity, and the results deduced have been the admiration of successive generations of astronomers and mathematicians.[7]

Newton's universal law of gravitation is: any two particles of matter in the universe attract one another with a force which is directly pro-

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[6]Bell, _Men of Mathematics_ (New York, 1937), pp. 95-97.

[7]Brodetsky, _Sir Isaac Newton_ (Boston, 1928), pp. 73-103.

portional to the product of their masses and inversely proportional to the square of the distance between them. Newton's second law of motion can be stated in this manner: the rate of change of momentum is proportional to the impressed force and takes place in the line in which the force acts.

The most important thing for mathematics in all of this is the idea of rate of change. What is a rate and how shall it be measured? His solution of this problem - giving a workable mathematical method for investigating the velocity of any particle moving in any continuous manner, no matter how irregular, gave him the master key to the whole mystery of rates and their measurement, namely, the differential calculus. A similar problem gave him the integral calculus. How shall the total distance passed over in a given time by a moving particle whose velocity is varying continuously from instant to instant be calculated? Answering this or similar problems involved the integral calculus. Finally, considering the two types of problem together, Newton made a significant discovery. He saw that differential and integral calculus are intimately and reciprocally related by what is today called the fundamental theorem of the calculus.[8]

A manuscript dated May 20, 1665, shows that Newton at the age of twenty-three had sufficiently developed the principles of the calculus to be able to find the tangent and curvature at any point of any continuous curve. He called his methods "fluxions" from the idea of "flowing" or variable quantities and their rate of "flow" or "growth". His discovery of the binomial theorem, enough in itself to have insured him of lasting fame, and necessary for a fully developed calculus, preceded this.

If one story is true, developing the calculus to an extent necessary to expand his universal law did not come easy for Newton. The story is that the twenty year delay in publication of his universal law had as its basis his immediate inability to solve a problem in the integral calculus which was crucial for the whole theory. Newton had to find the total attraction of a solid homogeneous sphere on any mass particle outside the

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[8]Bell, Men of Mathematics (New York, 1937), pp. 94-95

sphere. For every particle of the sphere attracts the particle outside the sphere. How were all these separate attractions, infinite in number, to be added into one resultant attraction. This problem lends itself to the integral calculus. Newton finally solved it: the attraction is the same as if the entire mass of the sphere were concentrated in a single point at its center. This reduced the problem to finding the attraction between two mass particles at a given distance apart and the immediate solution of this as stated in Newton's law.[9]

The impact of the calculus on the advancement of mathematics and science cannot be over-estimated.

> The calculus of Newton and Leibniz at last provided the long-sought method for investigating continuity in all of its manifestations, whether in the sciences or in pure mathematics. All continuous change, as in dynamics or in the flow of heat and electricity, is at present attackable mathematically only by the calculus and its modern developments. The most important equations of mechanics, astronomy and the physical sciences are differential and integral equations, both outgrowths of the seventeenth-century calculus. In pure mathematics, the calculus at one sweep revealed unimagined continents to be explored and reduced to order, as in the creation of new functions to satisfy differential equations with or without prescribed initial conditions.[10]

Writers disagree as to what Newton might have accomplished the last part of his life had he devoted it to the study of mathematics instead of taking the government job as Master of the Mint. These opinions vary from perhaps nothing original would have been to perhaps it would have been tremendous. In keeping with the "superlative" theme, perhaps the quotation below is as valid a speculation as any:

> It is impossible to avoid a feeling of regret that Newton should have allowed himself to be persuaded to degrade his unrivaled talents by accepting a well-paid government post that robbed the world of his genius for a quarter of a century. Had he like Archimedes, given up all his long life and all his talents to science and mathematics, there is not knowing what further great advances in human knowledge might have been achieved in the

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[9] Ibid., pp. 94-95.

[10] Bell, The Development of Mathematics (New York, 1945), p. 134.

quiet seclusion of a Cambridge College. It is to the author of the Principia and the inventor of fluxions, and not to the Master of the Mint that the world looks back with gratitude and awe as the first mind in eighteen centuries that equalled the mind of Archimedes.[11]

[11] Alfred Hooper, Makers of Mathematics (New York, 1948), pp. 323-324.

CHAPTER IV

GAUSS

Carl Friedrich Gauss was born at Brunswick, Germany in 1777 and died at Gottingen in 1855. With Archimedes and Newton, Gauss is usually considered one of the three greatest mathematicians in history. Even during his lifetime, he was described as "the prince of mathematicians". He possessed in an unusual way the supreme qualities of genius: creative ability and insight into the essential features of a problem; appreciation of the highest possible rigor in reasoning; reasonable accuracy and rapidity of computation and the will to carry through long computations; an understanding of physical ideas that made it possible for him to understand the various points of view of the mathematician, the theoretical physicist and the experimentalist; and the ability to expound his results with mathematical clarity and logical completeness.[1]

Gauss was the last of the great mathematicians who were able to handle every branch of mathematics. It is difficult to discuss in a limited space, even in general terms, all his works. The first important advance in Euclidean constructions for more than two thousand years was made by Gauss when he found the general criterion for a regular polygon of n sides to be constructible by ruler and compass. He was the first to give a rigorous proof of the fundamental theorem of algebra and gave several more during the course of his life. His main interest was in the field of arithmetic, or theory of numbers. Gauss' book Disquisitones Arithmeticae is a masterpiece on this subject. This work inaugurated a new era in the study of number theory, and in the hundred years that followed there were few discoveries in this field which cannot be traced directly to the investigations of Gauss. Although very little was published, he was in possession of much of the knowledge about elliptic functions that was made public later by other mathematicians. Through

[1]Gauss, Carl Friedrich, Encyclopaedia Britannica (Chicago, 1958), X, 76.

his youthful attempts to prove Euclid's parallel axiom Gauss was led to create the first non-Euclidian geometry.

Even though he is esteemed more highly for his contributions in the field of mathematics, Gauss spent most of his life studying astronomy. His brilliant calculations of the orbit of the minor planet Ceres caused him to be made director of the observatory and professor of astronomy at Gottingen. In 1832 Gauss published a paper on the absolute measurement of magnetic quantities and helped construct the first electromagnetic telegraph.[2]

Gauss made contributions in both areas of mathematics, theoretical and applied but seems to have preferred the theoretical. Mention has been made previously of his calling arithmetic (theory of numbers) the "queen of mathematics". The essence of the comments that follow were made by Gauss in an astronomy lecture given while he was professor at Gottingen which seem to give credence to his preference for the theoretical or at least his disdain for completely utilitarian motives for learning.

In the study of every science it is conventional to ask of what use is the science. It is not a good sign if one hears this question repeatedly. It means a lack of harmony exists between the necessities of life and the resources for satisfying them; it is a silent confession of an unhealthy degree of dependence on those needs if one demands a justification for study of a science and cannot understand that there are people who study merely because for them it is a necessity. Our poverty proves such a manner of judging to be petty, narrow minded and a lazy way of thinking and an indifference and insensibility to the great and to that which honors humanity. It is catastropic to science to relate everything to physical well-being, to be indifferent to great ideas, and to have an aversion for effort due merely to pure enthusiasm for the thing in itself.[3]

The ancestors of Gauss were humble people--gardeners, stonecutters, bricklayers. It was only by a fortunate chance that he did not follow one of these trades. His father more or less expected this of him. From the standpoint of heredity, an uncle, Friederich, on his mother's side possessed traits of high intelligence but a premature death prevented him

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[2]Ibid

[3]Waldo Dunningham, Carl Friedrich Gauss (Baton Rough, 1937), pp. 69-70.

from having a prolonged influence on Gauss.

In all the history of mathematics no one approaches the precocity of Gauss as a child. Before he was three, he found a mistake in the calculations of his father's ledger. When he was ten, he mentally calculated the sum of one hundred numbers in an arithmetic progression without having been told the formula. His youthful genius was brought to the attention of the ruling Duke of Brunswick who subsidized the education of Gauss in college and at the University of Gottingen. Even after leaving the University, the Duke granted him a stipend in order that he could continue work on the Disquisitiones.

While in college, Gauss realized that the uncritical use of the binimial theorem might lead to absurdities. For example in the expansion of $(1 + x)^n$, if n is not a positive integer, the series is infinite, and in such a case certain restrictions must be imposed in order to insure the it shall converge to a finite limit. Before Gauss, it was not uncommon to find a mathematician arriving at such a result as $\frac{1}{2} = 1 - 1 + 1 - 1 + 1 \ldots\ldots$ This inspired Gauss to seek for rigor in all his work and to impress upon his successors its importance. Before leaving college, Gauss also had evolved the method of "least squares" by which the most likely value of a variable quantity might be estimated from a large number of discordant observations.[4]

The topic Gauss used for his doctor's dissertation was the proof that every algebraic equation in one unknown has a root. What sort of root was made precise by proving that all the roots of any algebraic equation are "numbers" of the form a + bi, where a, b are real numbers and i is the square root of -1. Gauss showed the importance he attached to this theorem by giving four distinct proofs during his life. He was one of the first to give a coherent explanation of complex numbers and to interpret them as being the coordinates of points in a plane as is done today in algebra.

The Disquisitiones Arithmeticae was the first of Gauss' masterpieces and considered by some to be his greatest. It was published in 1801 when he was twenty-four and ended the era in which Gauss had completely used his talent in the field of pure mathematics. After this, his work also included astronomy, geodesy, and electromagnetism in both mathematical

[4]J. F. Scott, A History of Mathematics (London, 1958), pp. 207-208.

and practical aspects.

The Disquisitiones consisted of seven sections, the first devoted to the theory of congruences. These are defined in words by: if a number, a, measures the difference between two numbers, b and c, b and c are said to be congruent with respect to a, if not incongruent; a is called the mudulus, and each of the numbers b and c the residue of the other in the first case, the non-residue in the latter case.[5] The second section deals with the congruences of first degree and the third with the residues of powers. In the fourth section are introduced congruences of the second degree, with explanations of quadratic residues and quadratic non-residues. These sections led up to what Gauss described as the "supreme theorem"— the law of quadratic reciprocity. The fifth and sixth sections deal with binary and ternary quadratic forms.

In the final section, sometimes considered the crown of the work, Gauss applies the preceding results to a discussion of the algebraic equation $x^n = 1$, where n is any given integer, weaving together arithmetic, algebra, and geometry into one perfect pattern. The equation $x^n = 1$ is the algebraic formulation of the geometric problem to construct a regular polygon of n sides; the arithmetic congruence $x^m \equiv 1 \pmod{p}$, where m, p are given integers, and p is prime, is the thread which runs through the algebra and the geometry and gives the pattern its simple meaning. A new direction was given to the higher arithmetic with the publication of the Disquisitiones, and the theory of numbers, which in the seventeenth and eighteenth centuries had been a miscellaneous collection of unrelated special results, assumed coherence and rose to the dignity of a mathematical science on the same level with algebra, analysis, and geometry.

It was a disaster for mathematics that Gauss spent the better part of twenty years making astronomical calculations, just when he was entering the vast unknown which was to become the empire of modern mathematics. A new planet had just been discovered in a position that made observation extremely difficult. With the meager data available, it would be quite an accomplishment for someone to calculate its orbit around the sun and make it possible for astronomers to locate

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[5] Ibid., pp. 207-214.

it a year later. Newton had declared that such problems were among the most difficult in mathematical astronomy. Perhaps Gauss accepted the problem as a challenge. Whatever the reason, he calculated, and Ceres was rediscovered exactly where the ingenious calculations of Gauss had predicted she must be found. Other planets were discovered and their orbits calculated.[6]

In 1809, he published his second masterpiece, Theory of the Motion of the Heavenly Bodies Revolving Around the Sun in Conic Sections, in which a complete discussion of the determination of planetary and cometary orbits from observational data lays down the law which for many years was to dominate computational astronomy. Great as it was, no essentially new discovery was added to mathematics, as might have been if Gauss had continued his arithmetic researches. Recognition came very quickly to Gauss after the rediscovery of Ceres. Laplace, another great mathematician, who usually complimented others very sparingly, hailed Gauss as the greatest mathematician in the world.

Gauss married Johanne Osthof when he was twenty eight. There were three children from this marriage, one who is said to have inherited his father's gift for mental calculations. Johanne died four years after their marriage, and Gauss married a second time, a marriage by which he had two sons and a daughter. Two of his sons came to the United States and settled in Missouri.

In 1808 Gauss' father died, and, prior to that, Duke Ferdinand, his financial benefactor for many years, was mortally wounded in battle with Napoleon. This had a profound effect on Gauss, who had a horror of death.[7] About this time, Gauss was forced to seek employment and was made director of the Gottingen Observatory. He could have obtained a teaching position, but seems to have preferred the observatory, since if offered a better chance for uninterrupted research.

The year 1811 could have been a landmark in mathematics, had Gauss made public his investigations of analytic functions of complex variables, the theory of which was one of the greatest fields of triumph in the nineteenth century. Vast parts of the theories of

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[6]Ibid., pp. 209-213.

[7]Bell, Men of Mathematics(New York, 1937), pp. 239-245.

fluid motion, mathematical electricity, and representation by conformal mapping are handled naturally by the theory of analytic functions. Gauss had what amounted to the fundamental theorem in a letter to a friend, but did not make it public. The following year, Gauss' work on hypergeometric series was published. Work on the laws of biquadratic and cubic reciprocity, which require complex numbers, was found in his posthumous papers. Equally significant advances in geometry and the applications of mathematics to geodesy, the Newtonian theory of attraction, and electromagnetism were also made by Gauss.

It has been mentioned previously that Gauss was the first to create non-Euclidean geometry. The problem of the parallel axiom was brought to his attention early in life. At first he tried to replace the axiom with a simpler one but failed. He then tried a parallel axiom contradicting Euclid's and then by deducting the consequences of this new axiom and the other nine of Euclid's, he arrived at some strange theorems. Rather than allowing the strangeness to frighten him, he made a conclusion which the great and the near-great had failed to consider. He decided there can be other geometries as valid as Euclid's. Gauss' work on non-Euclidean geometry was found among his papers after his death.[8]

It would take an extensive book, perhaps a longer one than would be required for Newton, to describe all the outstanding contributions made by Gauss to mathematics, both pure and applied. Chronologically, his principal fields of interest after 1800 were as follows: 1800-1820, astronomy; 1820-1830, geodesy, the theories of surfaces, and conformal mapping; 1830-1840, mathematical physics, particularly electromagnetism, terrestrial magnetism, and the theory of attraction according to the Newtonian law; 1841-1855, analysis situs, and the geometry associated with functions of a complex variable.

How was it possible for one man to accomplish this great mass of high order work? The modest answer of Gauss was that is others would but reflect on mathematical truths as deeply and continuously as he did, they would make the same discoveries. It seems to the writer that a less modest evaluation need be revised to "if others would

[8]Morris Kline, <u>Mathematics in Western Culture</u> (New York, 1953), pp. 413-419.

and could reflect as deeply lnd continuously on mathematical truths". The capacity for intense and prolonged concentration was part of his secret. Another part, one less easy to obtain, was innate mental genius. Gauss resembles both Archimedes and Newton in the ability to forget himself in the world of his own thoughts. In two further respects he also measures up to them, his gifts for precise observation and a scientific inventiveness which enabled him to devise the instruments necessary for his scientific researches. The combination of mathematical genius with first-rate experimental ability is one of the rarest in all science. Unlike Newton in his later years, Gauss was never attracted by the rewards of public office, even though he perhpas would have made an excellent minister of finance. Another source of Gauss' strength was his freedom from personal ambition. When rivals doubted his statement that he had anticipated them, Gauss did not exhibit his notes to prove his priority but let his word stand on its own merit. With the posthumous publication of these and his correspondence, all these disputes have been settled in favor of Gauss.[9]

His last years were filled with honor, but perhaps not so much as he had deserved. His mind was still alert and inventive almost to the end. With the beginning of the year 1855, he began to suffer from an enlarged heart and dropsy. Gauss died on February 23, 1855 at the age of seventy-eight. He lives everywhere in mathematics.

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[9]Bell, Men of Mathematics (New York, 1937), pp. 254-263.

CHAPTER V

A POSSIBLE TWENTIETH CENTURY MATHEMATICAL GIANT

Will there be another Archimedes, Newton, or Gauss? Has the twentieth century already produced a mathematician that in time will be classified with these three? This is an intriguing question that is not easy to answer. Perhaps after 1727 the conjecture could readily have been that there would be no one to compare with Newton. The invention of the calculus opened up fields for mathematical exploration that were impossible previously or perhaps did not exist. This, apparently, made the scope of mathematics approach boundlessness to such an extent that no one person could surely make all of it his domain. Then there was Gauss, who almost all agree, measured up to Newton in terms of mathematical greatness and was able to handle every branch of mathematics known at that time. The work that Gauss did in pure mathematics caused another tremendous expansion in the field of mathematics.

By 1870, fifteen years after the death of Gauss, mathematics had grown into an enormous and unmanageable structure, divided into a large number of fields in which it was possible only for specialists to understand. Even great mathematicians at most could be proficient in only a few of these many fields. This specialization has constantly grown. There has been reaction against it, and some of the most important achievements during the last century have been the result of a synthesis of different domains of mathematics. Such a synthesis was brought about in the eighteenth century by the works of Lagrange and Laplace on mechanics. During the nineteenth century, to this unifying principle was added the theory of groups and Riemann's conception of function and of space.[1]

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[1]Dirk J. Struik, A Concise History of Mathematics (New York, 1948), p. 269.

The difficulty in judging the relative greatness of a mathematician increases exponentially when he is not far enough removed in time for a proper perspective on his mathematical merit. It is not easy to tell immediately the significance of advances in pure mathematics and even more difficult to say whether or not these results will lend themselves to practical application, should one desire to evaluate this aspect of new findings. The three mathematicians already didcussed had these two things in common which have influenced opinions regarding their greatness: a command of the existing field of mathematics and the discovery or invention of new mathematics in both the pure and applied fields. The next mathematician to be discussed is near the "charmed trio". Had he been as strong in practical science as he was in theoretical, he might be considered as great as the other three.

Henri Poincaré was born in 1854, the year before Gauss died, at Nancy, France and died in Paris in 1912. He studied at the Ecole Polytechnique and got a degree in scientific mining. From 1881 until his death, he was professor at the Sorbonne in Paris. No mathematician of his period commanded such a wide range of subjects and was able to enrich them all. Each year he lectured on a different subject among which were: potential theory, light, electricity, conduction of heat, capillarity, electromagnetics, hydrodynamics, celestial mechanics, thermodynamics, probability. Together they present ideas which have been developed by others, while many still wait for someone to synthesize.

Poincaré's work falls into three main divisions; his work in pure mathematics, in astronomy, and in physics. Most important is his work in pure analytical mathematics. He took the main points of an existing theory, simplified it, and then developed it extensively. In this way he opened up new fields for the mathematician and gave new material to the mathematical physicist. In pure analytical mathematics, a good part of his work is on the theory of functions.

He developed automorphic functions, and his work on the "Fuchsian" functions he applied to the non-Euclidian geometry of Lobatchevski. He also wrote a number of papers on Abelian functions. Poincaré extended the work of Cauchy on differential equations. He worked with linear differential equations on the lines of Riemann and Fuchs and wrote a number of papers on the differential equations which occur in physics.

The key to the understanding of Poincaré's work may lie in his meditations on celestial mechanics, and in particular on the three body problem. It was in relation to these problems that Poincaré studied divergent series and developed his theory of asymptotic expansions, that he worked on integral invariants, the stability of orbits, and the shape of celestial bodies. His fundamental discoveries on the behavior of the integral curves of differential equations are related to his work on celestial mechanics. This is also true of his investigations on the nature of probability. Like Gauss, in whatever field he worked, one finds the stimulation of originality. Our modern theories concerning relativity, cosmogony, probability, and topology are all vitally influenced by Poincaré's work. No mathematician of the nineteenth century has had so much effect on the mathematics of the present century.[2]

Poincaré's ancestry, in terms of intellectual or cultural achievement, was much better than that of either Newton or Gauss. Both his father and grandfather were physicians and his uncle a lawyer and subsequently the president of the French Republic. Poincaré's mental development as a child was extremely rapid. Due to an attack of diphtheria when five, he was delicate and timid for years. His main diversion was reading, where his unusual talents first showed up. He read rapidly and could always remember exactly what he read. All his life he retained both spatial and temporal memory to a high degree.

Poincaré developed an extreme interest for mathematics when he was about fifteen. He worked out his mathematical ideas mentally and did not write it down until finished. He had one handicap in that he lacked manual dexterity. Due to this, he failed the final examination in geometry at college, which involved precise drawing. This inability to use his fingers skillfully was a great handicap in adult life in laboratory experiments in mathematical physics. Unlike Gauss, who would not leave a piece of work until it was com-

[2]Ibid., pp. 278-281.

plete in detail, Poincaré broke through the main difficulties and left the finishing touches for others less gifted to work out.

Few mathematicians have had the breadth of philosophical vision Poincaré had, and none is his superior in the gift of clear exposition. For the literary excellence of his popular writing, Poincaré was given the highest honor possible for a French writer, membership in the literary section of the Institute. Closely related to the philosophy of mathematics was his interest in the psychology of mathematical creativeness. The significance of his findings is that mathematical discoveries, small or great, are never generated spontaneously. They are preceded by preliminary knowledge and well prepared by labor, both conscious and subconscious. Without drudgery and a flash of "inspiration", discoveries are not made.

Poincaré was the last man, to the present time, to work with practically the complete field of mathematics, both pure and applied. The general opinion is that it would be impossible for one person starting now to understand comprehensively, much less do creative work of high quality, in more than two of the four main divisions of mathematics— arithmetic, algebra, geometry, and analysis. This does not include astronomy and mathematical physics.

As has been briefly mentioned previously, mathematics both expands and contracts as it evolves. Unifying concepts are of tremendous importance as the mass of specialized mathematics increases. The introduction of extensive postulational methods in algebra makes the subject more abstract, more general, and less disconnected. In this way many of the specific and difficult things are consumable under simpler general principles of wider scope. Another example of synthesis in an age of explosive expansion is the use of tensor calculus in preference to different kinds of vector analysis. This quality of inclusive generality was a distinguishing trait of Poincaré's vast amount of mathematical work.[3]

Is there a contemporary mathematician who merits the distinction of being classed with the greatest? If there is, some time must elapse before he is universally acclaimed as such. It seems to the writer that if one is present, the acclaim will be given on the basis

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[3]Bell, Men of Mathematics (New York, 1937), pp. 526-548.

of the impact made by work done in a specialized area and its application rather than universality in the field of mathematics. According to one classification, there are at present eighty extensive branches of mathematics. Another possibility in obtaining the status of greatness of the highest order is for a mathematician to synthesize the field of mathematics with unifying concepts to the extent that universalism in mathematics would again be possible. On second thought, this illustration is somewhat contradictory, since the performance of this feat could perhaps be done only by a universalist. The writer lets the point rest in this respect.

The evolution of mathematics proceeds without ceasing. The rate of change is so great that perhaps revolution is the appropriate word to describe the change. One cause of the current pace is due to the outstanding advances made by mathematical research. The twentieth century has rightly been called the golden age of mathematics, since more mathematics, quantity and quality, has been created in this period than during all the rest of history. This century has witnessed the introduction and extensive development of subjects in pure mathematics such as abstract algebra, topology, measure theory, general theories of integration, and functional analysis, including the theory of Hilbert space.

Rapid development in areas of applied mathematics has also taken place. Some of these are probability and statistics, theory of games of strategy, and linear programming. The introduction of the large-scale, high speed, automatic digital computing machine has been a major factor in this advancement. This computer has made it possible for mathematical theory to be teamed with the machine to get quickly answers that are required by physicists, engineers, and others. The importance of the computer is not that it can do calculations quicker than has been done before but that certain calculations that were previously impossible can now be done with relative ease. A dramatic example is the part computers play in guiding missiles. In their exploration of linear programming, mathematicians have encountered many real-life situations, such as the operation of an oil refinery, that require matrices as big as 200 rows by 1,000 columns. By manipulating the matrix, a mathematician cam arrive at optimal plans to perhaps maximize profit. Manipulating such an enormous matrix requires 80 million separate multiplications.[4] It is an interesting though to wonder what effect a modern computer and a programmer would have had on the mathematical output of Gauss.

The quotation below from Bell was made prior to 1937 but seems appropriate for the present:[5]

> Today mathematical invention is going forward more vigorously than ever. The only thing, apparently, that can stop its progress is a general collapse of what we have been pleased to call civilization. If that comes, mathematics may go underground for centuries, as it did after the decline of Babylon; but if history repeats itself, as it is said to do, we may count on the spring bursting forth again, fresher and clearer than ever, long after we and all our stupidities shall have been forgotten.

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[4] G. Baley Price, Progress in Mathematics and Its Implications for the Schools,

[5] Bell, Men of Mathematics (New York, 1937), p. 18.

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