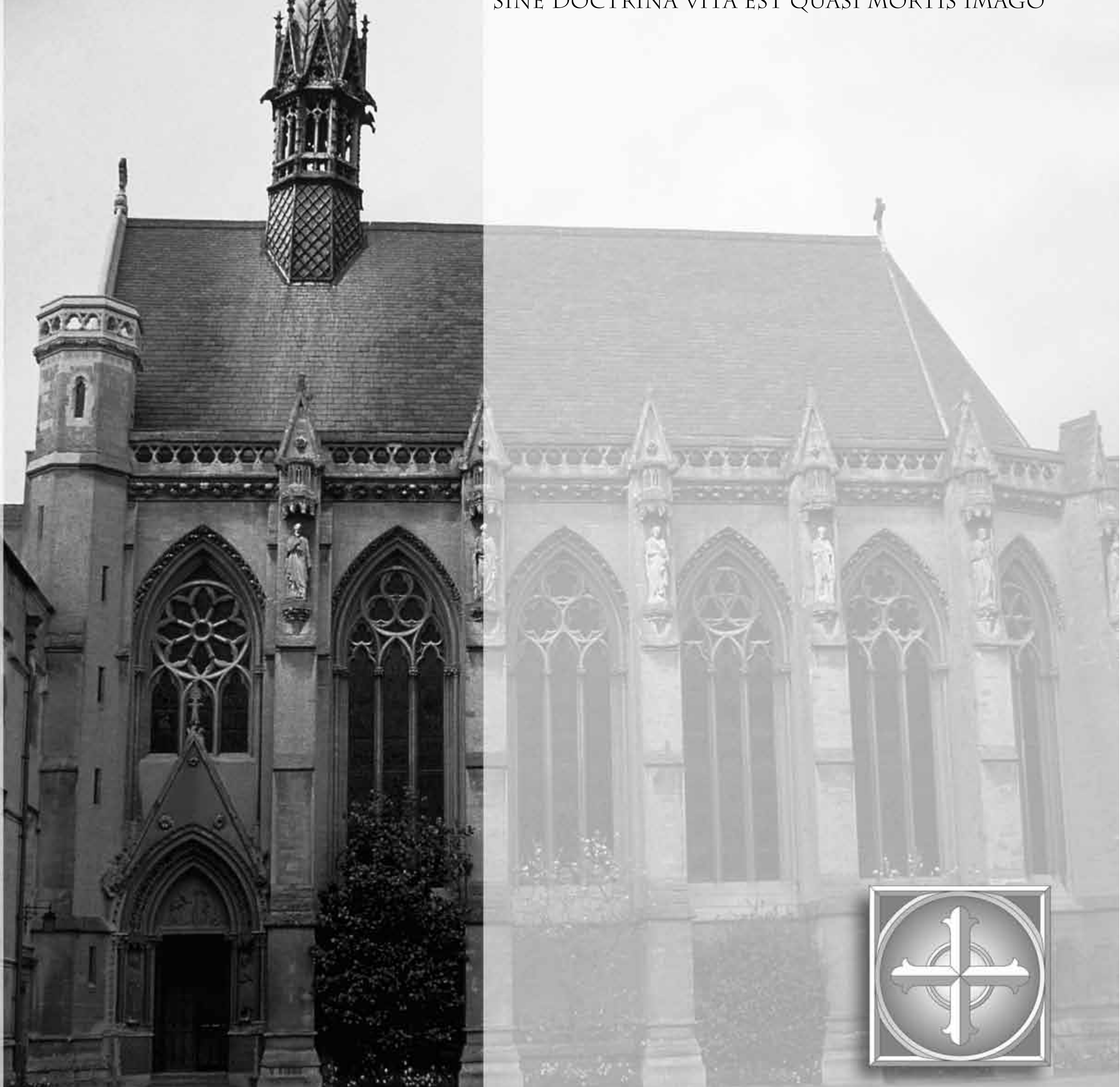
CLASSIS

THE QUARTERLY JOURNAL OF THE
ASSOCIATION OF CLASSICAL & CHRISTIAN SCHOOLS
SINE DOCTRINA VITA EST QUASI MORTIS IMAGO



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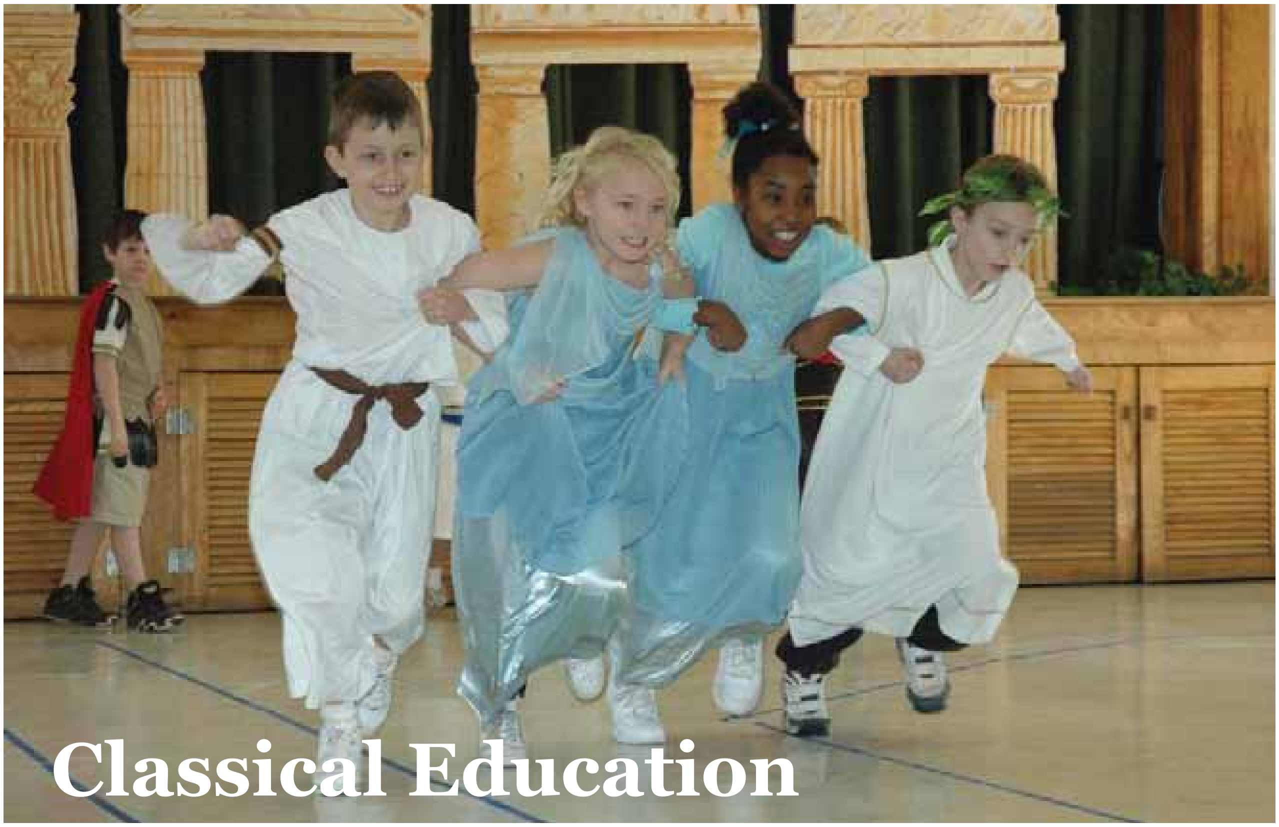

Classical Education

From its beginning, ACCS has advocated as its definition of "classical" the form of education that Dorothy Sayers described in her 1947 essay, *The Lost Tools of Learning*, and subsequently popularized in *Recovering the Lost Tools of Learning* by Douglas Wilson. Both of these authors advance the pedagogical methodology of the Trivium, which includes three aspects: grammar, dialectic, and rhetoric. Further, ACCS advocates, along with Miss Sayers and Mr. Wilson, that children tend to grow through developmental stages that generally coincide with the three areas of the Trivium. Children that are taught with these developmental stages in mind are receiving an education using classical methodology.

But there is another aspect to this, and that is to teach children their Western heritage through reading the great works of the West. These books provide the classical content. Such books are necessary to appreciate the arguments that have formed the way we think. This is so that our children can adequately provide the Christian antithesis to the humanistic arguments of our heritage that are still being advocated by our godless culture today. ACCS willingly acknowledges that it has a defined understanding of what constitutes a classical education and seeks to encourage that concept without apology.

Excerpt from the ACCS Position Paper: "What Constitutes 'Classical & Christian' for ACCS?" The entire paper is available at www.accsedu.org > About.

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ACCS

CLASSICAL CHRISTIAN EDUCATION FOR THE WORLD

CLASSIS is a quarterly journal of articles and book reviews designed to support and encourage schools around the world which are recovering classical Christian education. Hard copies are available to ACCS members and by subscription.

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The primary mission of this association is to promote, establish, and equip schools committed to a classical approach to education in light of a Christian worldview grounded in the Old and New Testament Scriptures.

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Sand on the Seashore

by Patch Blakey

While science is the human examination of God's created order, mathematics might be described as the quantifying of what is observed in creation. However, mathematics actually goes far beyond measuring the observed realities of creation to developing conceptual aspects of human imagination. Mathematics, speaking in general terms, is not only a quantifying process, but also a creative process. I will only address a small portion of the quantifying nature of mathematics.

After Abraham was willing to offer his only son Isaac to God as a sacrifice, the Lord told Abraham, ". . . By myself have I sworn, saith the LORD, for because thou hast done this thing, and hast not withheld thy son, thine only son: that in blessing I will bless thee, and in multiplying I will multiply thy seed as the stars of the heaven, and as the sand which is upon the sea shore; and thy seed shall possess the gate of his enemies; and in thy seed shall all the nations of the earth be blessed; because thou hast obeyed my voice" (Genesis 22:16b-18). I've never looked on the internet to see if anyone has ever estimated what this number might be, assuming that both the number of the stars and the number of the sand on the seashore are equivalent. I would be curious to know if anyone has ever even estimated the number of grains of sand in one child's beach bucket.

I am always amazed when I hear that new galaxies have been discovered, which means that however many stars that we thought there were, there are now many more that we need to identify and quantify. The number is immense, probably imponderable. What are we to do with a number with tens—much less hundreds—of zeros after it?

Yet as large as the number of stars or grains of sand may be, it is fascinating to note that the people from the tribes of Canaan who camped together to fight against Joshua and the people of Israel were described like this: "And they went out, they and all their hosts with them, much people, even as the sand that is upon the seashore in multitude, with horses and chariots very many" (Joshua 11:4). In other words, it appears that it was a very large number, and the term "as the sand upon the seashore" is metaphorical to some degree.

Then again, in the days of King Solomon's reign, his people are quantified as follows; "Judah and Israel were many, as the sand which is by the sea in multitude, eating and drinking, and making merry" (1 Kings 4:20). This seems to be a fulfillment, in part, of God's promise to Abraham. Yet, again, in the New Testament, we learn that the actual number is larger yet because the Apostle Paul wrote to the Galatians, "And if ye be Christ's, then are ye Abraham's seed, and heirs according to the promise" (Galatians 3:29). And that was nearly two thousand years ago. We now have two millennia more of those who are Christ's, and who knows how many millennia more?

We have yet to speak of counting the number of fingers and toes on the giant Goliath, or the size of the bedstead of Og, king of Bashan. The Lord has quantified much for us in the Bible that is fascinating! And yet there is so much more of His creation that yet defies quantifying. And even in the quantifying, this is not the explanation of what we see, but only a numeric place holder that helps our finite understanding.

In this issue of *Classis*, a number of knowledgeable and thought-provoking math and sciences instructors have authored several stimulating articles. I hope that you will find them of benefit as you read and consider their comments, and that they will stimulate you to further love and good works in your classrooms.

Patch Blakey *is the ACCS executive director.*

Francis Bacon's "Four Idols"

by Phil Arant, Schaeffer Academy

In viewing the original frontispiece from Francis Bacon's 1620 work *Novum Organum* ("New Method"), the observer is intended to notice ships leaving the familiar waters of the Mediterranean and venturing out into the vast Atlantic. The analogy implies that Bacon's new empirical (experimental) approach for explaining reality was intended to replace Aristotle's former deductive approach of logic endorsed in his *Organon*. In other words, an old limiting method needed to be replaced with a new limitless method.

Before providing an explanation of what would become an early version of the Scientific Method in Book II, Bacon first turns his guns upon some of these limiting mindsets and warns in Book I of four precommitments or "idols" that could jeopardize the objectivity intended within experimentation. Here's how Bacon named them.

> Four species of idols beset the human mind, to which for distinction's sake we have assigned names, calling the first Idols of the Tribe, the second Idols of the Den, the third Idols of the Market, the fourth Idols of the Theatre.[1]

Though I could spend some time here stressing how individuals can never completely avoid these "idols," I still find Bacon's breakdown quite enlightening for my science students. Let's consider each of the four issues and see how they can indeed do harm to the scientific enterprise.

First the *Idols of the Tribe* represents inherent tendencies of humanity that are fostered by the consensus of my surrounding community. The preferences of my "tribe" weigh heavily upon my conception of truth. If everyone says it is true, then in order to fit in I feel obliged to concur. Bacon analogously compared such an ill-fated persuasion to an uneven mirror that tends to distort incident light.

Frontisepeice from Francis Bacon's *Novum Organum*

> The idols of the tribe are inherent in human nature and the very tribe or race of man; for man's sense is falsely asserted to be the standard of things; on the contrary, all the perceptions both of the senses and the mind bear reference to man and not to the universe, and the human mind resembles those uneven mirrors which impart their own properties to different objects, from which rays are emitted and distort and disfigure them.[2]

Because of such an attachment to "the very tribe or race of man," we might consider the problematic issue to be one of *ethnocentrism*. If the human "tribe" is "falsely asserted to be the standard of things," then the scientist could be persuaded away from an interpretation that is consistent with his data. This faulty precommitment is sometimes referred to as an *argumentum ad populum*, which means "an argument from the populous." Thus, if many believe so, it is so. Perhaps you have noticed how the *Idols of the Tribe* have been influential in the current debate on global warming. "Tribe" consensus could distort (as with an uneven mirror) an objective attempt to interpret global temperature trends. John Locke also pointed at the same fallible tendency of trusting the group instead of embracing truth for its own sake.

> I mean the giving up our assent to the common received opinions, either of our friends or party, neighborhood or country . . . Other men have been and are of the same opinion, and therefore it is reasonable for me to embrace it.[3]

Secondly, the *Idols of the Market* represent errors arising from the false confidence bestowed upon word usage. In Bacon's day, the marketplace was a locus for verbal intercourse. Language could be handled carelessly to the point of creating a confusion of meaning. Let's again look at Bacon's wording.

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Francis Bacon . . .

> There are also idols formed by the reciprocal intercourse and society of man with man, which we call idols of the market, from the commerce and association of men with each other; for men converse by means of language, but words are formed at the will of the generality, and there arises from a bad and unapt formation of words a wonderful obstruction to the mind.[4]

Placing too much faith upon language can produce difficulties referred to as fallacies of ambiguity. One such problem would be found in *equivocation*. Words can often have more than one meaning. For example, the word "evolution" can lead to a commonly abused misunderstanding whether the speaker is referring to the phenomena of microevolution or macroevolution. Another problematic example is the postmodern emphasis that all words mean what the reader thinks regardless of what the writer intends.

Thirdly, the *Idols of the Den* represent errors that arise within the "cavern" of each unique individual rather than the entire "tribe" of humanity. Personal desires can lead to a type of egocentrism that could derail one's thinking.

> The idols of the den are those of each individual; for everybody in addition to the errors common to the race of man has his own individual den or cavern, which intercepts and corrupts the light of nature, either from his own peculiar and singular disposition, or from his education and intercourse with others, or from his reading . . . [5]

Through a life of personal accumulations, the individual has erected a particular habit or "taste" for data that accommodates his own delights. John Locke pointed at the same tendency with the phrase "*Quod volumus, facile credimus*," which can be translated "What suits our wishes, is forwardly believed."[6] Ancients as well played upon the supposed friendship that Aristotle enjoyed with his mentor Plato with the phrase, "*Amicus Plato, sed magis amica veritas*," which reads "Plato is my friend, but truth is a better friend. " Delights in maintaining a friendship could hinder our commitment to truth. Immanuel Kant also noted the danger of allowing a personal benefit to influence how we draw conclusions.

> Now to this one might indeed reply that no inquisitiveness is more detrimental to the expansion of our cognition than the inquisitiveness that always wants to know the benefit in advance.[7]

A derivative notion of this third precommitment might be found in the fallacy termed *argumentum ad baculum*, which means "the argument to the stick." Here the "stick" refers to taking a beating. In other words, the particular statement had better be endorsed or else some undesirable consequence will impact me. Because I don't want my "den" shaken, I will hold it as true.

Lastly the *Idols of the Theater* represents the theories that have been "played out," as on the "stage" by the renowned performers of our culture. I, the lowly spectator, become moved by the eloquence of the "experts" of the past. These are the sacred truths that have been passed down to our generation. The theater could thus impose a rigid dogmatism upon a culture.

> Lastly, there are idols which have crept into men's minds from the various dogmas of peculiar systems of philosophy, and also from the perverted rules of demonstration, and these we denominate idols of the theatre: for we regard all the systems of philosophy hitherto received or imagined, as so many plays brought out and performed, creating fictitious and theatrical worlds . . . but also to many elements and axioms of sciences which have become inveterate by tradition, implicit credence, and neglect.[8]

Aristotle, by means of his works such as *Organon, Physics,* and *Metaphysics*, would be considered a noteworthy "player" in Western civilization. For hundreds of years, the conclusions attributed to Aristotle were not questioned. Such a problematic precommitment could be targeted by the reasoning fallacy termed *ipse dixit* ("he said it himself") or more pointedly *magister dixit* ("the teacher has said it"). Here an unproven statement is dogmatically accepted on faith in the speaker. Questioning is set aside.

I would thus summarize Bacon's four presumptive dangers to the scientific process as the ethnocentrism of the tribe, the equivocation within the marketplace, the egocentrism of our den, and the dogmatism of the theater.

Yet what of the Scriptures? Could the unbeliever complain that God's supposed speaking

Francis Bacon . . .

jeopardizes objectivity as an Idol of the Theater? Our students must understand that for even Bacon's experimentalism to stand, it must also hold presuppositions. The inductive attempt to derive objective conclusions from numerous observations can never be completely "free" (as Bacon's ships in the Atlantic) of some non-empirical precommitment. For example, our scientific efforts must not only assume a uniformity (hence repeatability) of phenomena, but also assume that our senses are trustworthy in observing such uniformity. Experimental consistency cannot find justification apart from an imposed intentionality for the particulars of life. One must get outside the pieces of a jigsaw puzzle in order to realize that it is indeed a puzzle intending to be assembled. Some "meta-player" that stands above the process of existence must be assumed every time we conduct an experiment. God as transcendent can alone occupy such a stage. As C. S. Lewis famously stated,

> I believe in Christianity as I believe that the sun has risen: not only because I see it, but because by it I see everything else.[9]

With ultimate reliance upon a human *magister dixit*, questioning is jeopardized. With the Divine *magister dixit*, questioning is enabled.

Notes:

1. Francis Bacon, *Novum Organum,* Aphorism 39 (New York: P. F. Collier & Son, 1902), 19-20.

2. Ibid., Aphorism 41, 20.

3. John Locke, *An Essay Concerning Human Understanding*, Book Two, Chapter 11, Section 9 (New York: Barnes & Noble, 2004), 617.

4. Francis Bacon, *Novum Organum,* Aphorism 43 (New York: P. F. Collier & Son, 1902), 41

5. Ibid., Aphorism 42, 21.

6. John Locke, *An Essay Concerning Human Understanding*, Book Two, Chapter 11, Section 9 (New York: Barnes & Noble, 2004), 614.

7. Immanuel Kant, *Critique of Pure Reason*, trans. Werner S. Pluhar, (Indianapolis: Hackett Publishing Co. Inc., 1996) 304-305.

8. Francis Bacon, *Novum Organum*, Aphorism 44 (New York: P. F. Collier & Son, 1902), 21-22.

9. C. S. Lewis, *The Weight of Glory*, (New York: Harper Collins, 1980) 140.

Photo credit:

http://upload.wikimedia.org/wikipedia/commons/b/b2/Novum_Organum_1650_crop.jpg.

The Quest for Mathematical Truth

by Brett Edwards, Atlanta Classical Christian Academy

French mathematician Sophie Germain of the late eighteenth and early nineteenth centuries is considered one of the greatest female mathematicians of history. Germain was thirteen years old when the tumult and chaos of the French Revolution forced her to remain indoors. This confinement turned her attention to her father's library where she found a book of math history describing the apocryphal story of the death of Archimedes. It is often told that as Roman forces besieged the city of Syracuse during the Second Punic War, a Roman soldier approached Archimedes, commanding him to surrender. Archimedes was so absorbed in a mathematical diagram that he responded saying, "Don't disturb my circles." This sentiment can be understood and appreciated by math teachers around the world. Unfortunately for Archimedes and the world, the soldier decided to disturb his circles and killed the greatest mathematician of antiquity. Upon reading of Archimedes' demise, Germain was so impressed with his relentless devotion to mathematics that she committed to make it the pursuit of her own life. Her parents would often find her staying up all night working through calculations by candlelight on her slate. She would go on to become one of the pioneers of elasticity theory and for this work would win the grand prize from the Paris Academy of Sciences.

Although many human pursuits come and go, the quest for mathematical truth seems to persist throughout man's history—from Archimedes to Germain down to the present. What I find so fascinating about mathematics is its ability to so completely captivate and consume the human mind. What is so alluring about mathematics? Why were the minds of Archimedes and Germain so intent on finding truth in mathematics even to the point of death in the case of Archimedes? I would argue that one of the more engrossing characteristics of mathematics is its dual nature of being both comprehensible and incomprehensible. Man is attracted to those things that are both knowable and yet not fully comprehensible. While there is great fulfillment when a particular mathematical idea or concept is grasped, the student can return again and again to the inexhaustible field of mathematics.

. . . what makes mathematics particularly scintillating is that, consistent with the nature of God, there is an infinite region of mathematics incomprehensible to the human mind.

Albert Einstein remarked that "the most incomprehensible thing about the world is that it is at all comprehensible."[1] This understanding is consistent with Einstein's agnostic worldview. In a world without a creator, why should one expect the created order to be harmonious and comprehensible? Einstein's refusal to attribute the order of the world to a God of order is the dominant view of the intellectual elite in our secular culture. The unbeliever is confronted with this dilemma daily as he watches the sun rise, leaves fall, and plants grow in a predictable manner. Why does order exist in the world? The Christian sees the comprehensibility and the incomprehensibility of the created order as a reflection of God Himself.

The Christian math class ought to be a sanctuary for honest, open, and engaging discussion of both of these attributes. Our students have an innate longing for truth and should see the math class as another area to study the very nature of God. Nineteenth-century English mathematician Hilda Phoebe Hudson argued that "to all of us who hold the Christian belief that God is truth, anything that is true is a fact about God, and mathematics is a branch of theology."[2] Johannes Kepler said "the chief aim of all investigations of the external world should be to discover the rational order and harmony which has been imposed on it by God and which He revealed to us in the language of mathematics."[3] Such an understanding gives a hallowed purpose to every calculation and proof in the math class. What if the students in our classes had this view of their scientific studies? Such an understanding of mathematics would surely develop a wonder of and passion for truth in their studies.

It would be helpful to dig a

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The Quest . . .

little deeper into each of these attributes and their pervasive presence in mathematics. First, mathematics is an area in which God has provided us access to knowledge (comprehensibility). Throughout human existence we have been able to uncover mathematical truths which in turn are used for a host of creative human applications and endeavors. Our ability to find and comprehend these truths provides a great sense of achievement and fulfillment especially as the abstractions become more difficult and challenging. Consider the achievement felt by English mathematician Andrew Wiles upon successfully proving Fermat's Last Theorem in 1995.[4] A proof for this theorem had eluded the greatest minds for more than 350 years.

However, what makes mathematics particularly scintillating is that, consistent with the nature of God, there is an infinite region of mathematics incomprehensible to the human mind. Early in the twentieth century, mathematician David Hilbert and other prominent mathematicians of the time embarked on a "program" to eliminate all paradoxes and inconsistencies from the foundations of mathematics. In essence, Hilbert's pride in the intellectual potential of man propelled him to believe man could make logical sense of all complexities in the natural world. This view believed man could rise to the intellectual level of God. German mathematician and philosopher Kurt Gödel would eventually prove Hilbert's efforts to be logically impossible with his incompleteness theorems. These theorems would be another victory for the incomprehensibility of mathematics. Gödel's results shouldn't come as a surprise to the Christian but are a rather devastating blow to the progressive movement's hope and trust in the abilities of autonomous man.

Although there is an infinite supply of mathematical conundrums, two particular examples are sufficient to illustrate the incomprehensibility of mathematics. For thousands of years, man has been amazed and perplexed by the nature of prime numbers. These numbers are the basic building blocks of all natural numbers (positive whole numbers). There are an infinite amount of prime numbers and what is most fascinating is that they have no discernible pattern. Eighteenth-century Swiss mathematician Leonhard Euler concluded that "mathematicians have tried in vain to this day to discover some order in the sequence of prime numbers, and we have reason to believe that it is a mystery into which the human mind will never penetrate."[5] Twentieth-century Hungarian mathematician Paul Erdös agreed saying that "it will be another million years, at least, before we understand the primes." There are various conjectures related to prime numbers that continue to stump the brightest mathematicians in the world. Among them, Goldbach's conjecture states that "every even integer greater than 2 can be expressed as the sum of two primes."[6] Computers have found the conjecture to be true up to 4×10^{18} but no one has been able to provide a rigorous mathematical proof for this simple mathematical assertion. One can assume that prime numbers will continue to challenge human minds throughout time.

Euler's identity provides another impressive example of the incomprehensibility within the created order. The identity incorporates the five most notable constants of mathematics in a single equation stating that $e^{i\pi} + 1 = 0$. One poll conducted by a mathematical journal named Euler's identity the most beautiful theorem in mathematics.[7] Nineteenth-century American philosopher and mathematician Benjamin Peirce noted that the identity "is absolutely paradoxical; we cannot understand it, and we don't know what it means, but we have proved it, and therefore we know it must be the truth."[8] The Christian can connect such a statement to their limited understanding of the Trinity. Although we know the concept to be true, we cannot understand it.

At root, this passion for mathematical truth is an interest in God Himself. God is both comprehensible and incomprehensible. That this dual aspect is also revealed in creation through the language of mathematics should not be surprising to those of the Christian faith. The psalmist declares "the heavens declare the glory of God, and the sky above proclaims His handiwork. Day to day pours out speech, and night to night reveals knowledge" (Psalm 19:1, 2). The search for truth in mathematics has found complex and beautiful abstract models that explain the nature of the heavens, the sky, and all of creation. In describing the nature of this quest for the mathematicians of the sixteenth through eighteenth centuries, secular math historian Morris Kline says, "Indeed, the work of 16th-, 17th-, and most of 18th-century mathematicians was . . . a religious quest. The search for mathematical laws of nature was an act of devotion which would reveal the glory and grandeur of His handiwork."[9] I believe one of the great opportunities for the Christian math teacher is to appropriately frame the work of their class in this light. They are to communicate clearly the connection between mathematics and the nature of God. When this connection has been made they can then embark on mathematical adventures revealing the intricate complexity of God's world. In finding the rational order behind God's creation, the student can truly experience and enjoy the glory and grandeur of God.

Notes:

1. Antonina Vallentin, *Einstein: A Biography*, (London: Weidenfeld & Nicolson, 1954), 24.

2. Hilda P. Hudson, "Mathematics and Eternity," *The Mathematical Gazette*, Vol. 12, No. 174 (Jan., 1925), pp. 265-270. Published online by the Mathematical Association, http://www.jstor.org/stable/3603647

3. Johannes Kepler, *Defundamentis Astrologiae Certioribus*, Thesis XX, 1601.

4. Simon Singh, *Fermat's Enigma*, (New York: Anchor Books, 1998).

5. Leonhard Euler, *Opera Omnia*, Series 1, Vol. 2, 241, edited by the Euler Commission of the Swiss Academy of Science in collaboration with numerous specialists, 1911-. Originally begun by publisher B. G. Teubner, Leipzig and Berlin. Birkhäuser, Boston and Basel, has continued publication.

6. Eric W. Weisstein, "Goldbach Conjecture," Wolfram MathWorld, http://mathworld.wolfram.com/GoldbachConjecture.html

7. Paul Nahin, *Dr. Euler's Fabulous Formula: Cures Many Mathematical Ills*, (Princeton, NJ: Princeton University Press, 2011), 2-3.

8. Edward Kasner and James Newman, *Mathematics and the Imagination*, (Mineola, NY: Dover, 2001), 103-104.

9. Morris Kline, *Mathematics: The Loss of Certainty*, (New York: Oxford University Press, 1982), 34.

2012 Chrysostom Oratory Competition

Champion
Phoebe Hu
Tall Oaks Classical School

Runner-Up
Daniel Dawson
Rockbridge Academy

Congratulations, Phoebe and Daniel!

Imitating Consistency: Math as Character Formation

by Charlie Dowers, The Oaks: A Classical Christian Academy

The other night I took my family to the park. It was a warm, Sunday evening for fall and our only goal was to enjoy the outdoors together. My two-year-old son loves such outings: long paths for running, a water fountain, and of course, big, open, grassy spaces. This particular Sunday, we happened to bring a soccer ball with us as well. The water fountain was interesting and the paths adventurous, but the grass became the playground. "Do again, please!" my toddler laughed as I kicked the soccer ball up into the air as many times as possible before letting it hit the ground. To say that my son enjoyed watching me run around, trying to keep a ball in the air, sells his response short. One time, after the ball hit the ground just out of my reach, I looked at my son expecting another "do again!" and wondered if I could keep going. Instead, I saw him doubled over, laughing so hard that the sound had stopped. We had both proved G. K. Chesterton right: I was not strong enough to exult in monotony, but my son loved it. Chesterton, in praise of the child's delight in repetition, gives the example of the sunrise: "It is possible that God says every morning, 'Do it again,' to the sun."[1] God's childlike glee in continually exhorting the sun to shower the earth with its rays results in both "flakes of flame" in the sky—to borrow again from Chesterton—and the time-keeping precision of a new day's sunrise.

As math teachers, we desire to cultivate this same love for the creation in our students. We hope that through our instruction in math class they will delight in the world God has created in new and deeper ways. In other words, we hope our lessons "soak into their bones" and change them. we usually associate a sunrise with fantastical colors and poetry, math dials in on this marvel at another frequency. Math elaborates on the precision in God's glee-filled command that the sun rise again.

> *Ten years in a math class can equip students with the training and skills necessary for calculus and it can also open up their hearts and affections to lovingly embrace consistency itself as a characteristic of God . . .*

Our goal in every class is to effect character changes in our students. But for us as teachers, there seems to be a rift between instruction in math class and changes in character. Stating that education is character formation sounds right, but how are we supposed to be forming the delights of our students while teaching trigonometry identities, fractions, and functions? How do we go beyond "getting the right answer"?

A right answer is a worthy goal and deserves full credit on a test; however, the value in the problem extends further than mere credit towards a grade. The value includes how that correct answer changes us. We have gone beyond valuing the right answer as the ultimate good when doing math starts shaping our character. So what is there in a math problem that affects who we are? The answer makes a lot more sense when it is connected to a concrete illustration. One thing Chesterton highlights in a sunrise is the repetition of the event. And while

Think for a moment about how consistent God's command to the sun to "do it again" actually is. We don't have to contemplate for long before we reach for numbers to express the level of precision. Expressing precision may in fact be what math does best. And in so doing, math underscores a very particular aspect of God's fingerprint by showcasing the depths of God's consistency. And this line of thinking propels us past mere accurate calculations. We begin to see more than numbers and logic; we see a facet of the very character of God made manifest.

Applying math to a sunrise—or any aspect of the real world—reveals God's consistency. In an ironic twist, though, it not just the physical world that is real; abstract math is real. Consider, for example, trigonometry. As a branch of mathematics, trigonometry primarily describes how triangles work. Most of our lives, we walk around confident that a triangle is merely a three-sided polygon. And even though the definition of a triangle never changes, understanding how those three sides relate to one another holds potential for endless study.

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Imitating Consistency . . .

All over the Scriptures we read of God having made the world and all things therein (*e.g.*, Gen. 1; Acts 17:24). If God made the world, and if God made triangles, then it follows that He made the relationships between the sides of the triangle as well. Trigonometry is real because God fashioned and upholds these relationships; we can study them as God-breathed works. When we believe that math is a work of God just like the next sunrise, when we believe that math shows His consistency, when we expect that it has divine fingerprints all over it, math becomes another chapter of God's grand story to reveal Himself to us.

The expectation then, entering a math classroom, is that we are studying real works of God in the concepts before us. Think about a twelfth-grade math class; by that point, the students have spent at least ten years of their lives studying the subject. It has been one extended exercise in highly precise applications of consistency. Homework problems, one after another, have assumed Christ holds relationships constant. The students are saturated with consistency. So how could the study of these works of God shape them? If education is really more about formation than information, how could ten years of math problems shape students more into the image of Christ? Illustrations of consistency applied to our lives are plentiful in Scripture. Psalm 15 describes a righteous man as one who follows through on a promise even when it hurts. Keeping our word manifests consistency. Consistency is required when, in the fourth commandment, we are told to honor the Lord by resting one day out of every seven. Even general principles of Christian living like the spiritual disciplines presume consistency. Ten years in a math class can equip students with the training and skills necessary for calculus and it can also open up their hearts and affections to lovingly embrace consistency itself as a characteristic of God which they want to imitate. In essence, the students' character can be refashioned by studying math this way.

Though character formation cannot be achieved by checking off a box, any math lesson can provide fodder for a new love. Let's look at a math lesson about the Side-Angle-Side property of triangles. Often the goal for this lesson culminates in successfully completing homework problems. But if we stop there, we are neglecting much of what God has created in these relationships. As C.S. Lewis said, "Education without values, as useful as it is, seems rather to make man a more clever devil."[2] A lesson on the Side-Angle-Side (SAS) property of triangles must be mastered by the student both in application to the homework problem and in relation to the glory of God. This is a "both/and" scenario: math proficiency and biblical worldview. Why would we want to stop short in either category—be it not understanding what God has made or not giving Him credit for it? What if our students could learn the Side-Angle-Side property, know that this too is a work of God, explain how it shows His fingerprint, and get their homework problems right? What might that kind of learning look like? Suppose in the last five minutes of class students wrote a paragraph explaining the SAS property in which they accurately utilized their math terms and clearly described an application of the principle. What if they then went on to cite Acts 17:24 to explain why this property existed, thanked God for His example of consistency, and asked for the strength to imitate God's character in this way? Might not such a request to imitate God's character suggest a new love or desire in the heart of the student?

As we know in our own walks with the Lord, imitating God is difficult because it requires us to change. Last summer, I remodeled my home. One of my least favorite parts of the project was insulating the walls and ceiling—I found it tedious and tiresome. After completing the project, I talked with a fellow teacher about building houses. He told me of a man he met who worked full-time insulating houses. When my teacher friend had asked the man what it was that he most loved about his job, he replied, "The variety." Granted, I have only insulated the walls in my own house, but to me, the job had no variety—measure, cut, staple, repeat. For many math students, hearing the statement "God is consistent, logical, and orderly," or even simply working on a math problem elicits the same response as I have to insulating walls. Even with conscious efforts on my part to the contrary, once I begin to insulate and my arms start to itch, my patience evaporates and I just want to get the job done. Have students ever described a math assignment to you in comparable terms? For me to overcome this negative reflex requires that the old thinking be replaced by a new habit. In other words, I need to be reshaped and to develop a new love. In math class, we labor to

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Leaders in Science and Technology from Christian Classical Education

by Steve Lewis and Keith Phillips, Schaeffer Academy

The Apostle Paul teaches us to do all to the glory of God. Augustine teaches us that nothing is evil—evil is the absence or abuse of things. Luther teaches us that any type of work may be pursued by the Christian as a vocation. Kuyper teaches us that "there is not a square inch in the whole domain of our human existence over which Christ, who is Sovereign over all, does not cry: 'Mine!'"[1] And, Schaeffer teaches us that "Christianity is not a series of truths in the plural, but rather truth spelled with a capital 'T.' Truth about total reality, not just about religious things."[2] These lessons persuade us that Christians should be involved in every legitimate field of endeavor.

The biblical accounts of Joseph and Daniel further persuade us that much good can come from Christians holding positions of leadership—even leadership in cultures and institutions which are predominately idolatrous. In today's world, the science and technology industries are hugely influential and often idolatrous. Yet, some Christians should be prepared to become a Joseph or a Daniel within these industries, and the Christian classical school should play a part in preparing these future leaders.

Doing so will require a commitment to participation for the sake of blessing. It will require a commitment of resources. It will require creativity, thoughtful implementation, and ongoing conversations. In the hope of stimulating these conversations, we will briefly discuss current requirements for attaining top leadership in the science and technology industries, the role of the Christian classical school in preparing some students for such leadership, and some specific strategies we are implementing at Schaeffer Academy.

Current requirements

The process of attaining a top leadership position within the science and technology industries starts early. Successful organizations select a set of universities that they believe will offer them the strongest employees. They go to those campuses and hire only the top math and science students. They contact professors and ask, "Who are your best and brightest?" Sometimes, they search for top students by bringing them into undergraduate internship programs. *Therefore, being prepared to quickly reach the top of the math and science classes in the universities where industry recruits is a requirement for top leadership in the science and technology industries.*

Once hired, each individual is evaluated for several years. The employee is compared to the other top college graduate employees. There are no overt tests. Rather, supervisors subjectively evaluate each individual's ability to grow the impact of the organization. Only the top 30–40% will advance. *Therefore, being prepared to flourish in a context of constant and intense competition is a requirement for top leadership in the science and technology industries.*

Those who advance, move into an even more difficult competition at this point. They are given more responsibilities and assigned to "leading edge" projects. These projects have specific goals but vaguely defined processes and teams. They are expected to invent solutions on a schedule. They are evaluated on their ability to sell their ideas to their peers with minimal management support and to achieve the goals that they have created for their teams. *Therefore, being prepared to motivate others to work beyond merely following established rules and procedures is a requirement for top leadership in the science and technology industries.*

The small fraction that is successful at the previous levels is now well known to senior management and will be evaluated as potential replacements for existing top leaders. Their opportunity to advance is tied to their ability to grow the institution in completely new directions before they retire or die. This constitutes the final level of evaluation. Can the individual propose something new with such salesmanship that the institution is willing to risk its funds to make it happen? Does the person have enough credibility and commitment to the organization that leadership sees his or her proposal as the way of the future? *Therefore, being prepared for risk-taking and salesmanship is a requirement for top leadership in the science and technology industries.*

Institutions within the science and technology industries will not be turned over to the merely well-rounded or the good rule-follower. Top leadership will only be given to those who

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are prepared—and excel—in the ways mentioned above.

The role of the Christian classical school

The Christian classical school should not seek to prepare all of its students for leadership in the science and technology industries. Some should be prepared to become poets, professors, pastors, and plumbers. Some should be prepared to become honorable followers—good leaders need good followers. Nevertheless, the current requirements of the science and technology industries should not cause the Christian classical school to refrain from preparing some students for leadership in these industries.

We have already made our case for the appropriateness of Christian involvement in this field of endeavor. Some readers, who agree with that case in general, may still be skeptical of the role for the classical school in particular. Shouldn't classical schools be about the humanities, not the sciences? Shouldn't they be literary, not mathematical? Shouldn't they offer breadth, not specialization? These questions pose false dilemmas.

Within the Association of Classical and Christian Schools, the insight of Dorothy Sayers in "The Lost Tools of Learning" is generally regarded quite highly. In that essay, when discussing what she called the rhetoric stage of education, she wrote:

> Any child who already shows a disposition to specialize should be given his head: for, when the use of the tools has been well and truly learned, it is available for any study whatever. It would be well, I think, that each pupil should learn to do one, or two, subjects really well, while taking a few classes in subsidiary subjects so as to keep his mind open to the inter-relations of all knowledge.[3]

There is nothing "unclassical" about making it possible for some students to specialize in math and science or to develop the leadership skills required by the science and technology industries. To the contrary, for schools whose definition of "classical" includes Sayers' insight, it seems essential to encourage some specialization in the rhetoric stage.

Specific strategies

At Schaeffer Academy, we require all students to acquire the basic tools of learning before allowing specialization. And, even when they specialize, we require courses outside their area of specialization to remind them that knowledge is interrelated, to enrich their lives, and as part of their equipment for making a difference should they attain top leadership. Nevertheless, in eleventh and twelfth grade, we do allow students to specialize.

Juniors and seniors with the ability and desire to specialize in math and science can take Pre-Calculus, Calculus, Honors Physics, and Advanced Placement (AP) Physics. Those whose ability and desire better suits them for the humanities or the arts are only required to take one math course (Math in the Liberal Arts) and one science course (Physics I). These students are then able to pursue other disciplines more in line with their dispositions.

By offering, but not requiring the advanced math and science courses, we are able to move at a very rapid pace in these classes. We make them very challenging for the students who are so disposed, without needing to worry about bringing along those who are not. We also increase the level of competition among the students and the level of focus and commitment required for an average to above average grade. We assign work that requires unusually large time commitments and teaches students to prioritize time for a goal. This year, we plan to assign work that requires students to establish and manage teams. We also plan to offer extra credit opportunities which can only be attempted by the team with the best bid and have a penalty for failure. All of these things will help prepare students for the realities of leadership in the science and technology industries.

We currently only offer one College Board approved AP course, but as enrollment and funds allow, we plan to offer more. The requirements for some AP courses do pose challenges for the Christian classical school. Space does not allow us to address those

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challenges here. Nevertheless, we believe that it is beneficial to offer some of these courses in Christian classical schools. They stretch conceptual learning and force students to face tests that represent the current standards—standards they will have to deal with in the science and technology industries—under the supervision and care of a mature Christian teacher.

Indeed, for any of these strategies to enable participation for the sake of blessing, our entire curriculum must pass along a Christian worldview. Christian teachers must prepare students to decide—like Joseph and Daniel—when to function within the current system and when to oppose it. Our goal is not industry leadership at any cost: Christ is King. Nevertheless, when God opens the doors, some of our students should be ready to bring the lordship of Christ to bear as leaders in science and technology.

Notes:

1. Abraham Kuyper, "Sphere Sovereignty" in Abraham Kuyper: *A Centennial Reader*, ed. James D. Bratt (Grand Rapids, MI: Eerdmans, 1998), 488.

2. Quoted from Schaeffer's address at the University of Notre Dame in 1981 in the book by Nancy Pearsey, *Total Truth: Liberating Christianity from Its Cultural Captivity* (Wheaton, IL: Crossway Books, 2005), 15.

3. Dorothy L. Sayers, "The Lost Tools of Learning," a paper read at a Vacation Course in Education, Oxford, 1947. You may read this at accsedu.org/The Lost Tools of Learning.ihtml?id=633752.

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help our students understand concepts like the SAS property and eventually they get them. But how does that process shape them if it does not point them to God's eternal power and divine nature as Romans 1:20 proclaims? Can that mathematical concept begin to bear sweet fruit in their lives? Perhaps the better question is: does our life provide an example of the sweet fruit produced by going beyond the right answer?

As teachers we are keenly aware of the areas in which we fall short. Our lives are marred by sin and twisted by bad habits, so, not surprisingly, our example is flawed, too. And yet, Christ's incarnation interrupted history and gives us new life and new hope. Christ is not only the reason our marred efforts to teach have a chance of impacting hearts, but He is also the perfect embodiment of the consistency of God and the source of creation's consistency. "For from him and through him and to him are all things. To him be glory forever" (Romans 11:36 ESV). As we sit in Christ's classroom, we see that the God who is the same yesterday, today, and forever still never ceases to surprise. His consistency is perfect, but not routine. Children are conceived through the union of man and woman, yet once a baby was born of a virgin. A sunrise time can be predicted, but for Joshua one day the sun stood still. And even death, the end of all men, was conquered by one man. As we wrestle with bringing Christ's consistency to bear in our lives, we do so in a world charged with God's grandeur "shining forth like shook foil."[3] God throws himself into a sunrise, and as one man said, "Man was not made in God's image for nothing."[4] We will echo the delight of toddlers and the gratitude of the insulation installer because in the process of discovering and imitating God's consistency, His character will become ours.

Notes:

1. G.K. Chesterton, *Orthodoxy* (San Francisco: Ignatius Press, 1995), 65.

2. C.S. Lewis, *Abolition of Man* (New York: HarperCollins, 2001).

3. Gerard Manley Hopkins, "God's Grandeur," *Hopkins: Poems and Prose* (New York: Alfred A. Knopf, Inc, 1995), 14.

4. Robert Farrar Capon, *The Supper of the Lamb: A Culinary Reflection* (New York: Random House, 2002), 19.

Why Math Works: Answering Eugene Wigner, et al.

by John Mays, Regents School of Austin

Back in 1999 when I began teaching in a classical Christian school, one of the first books I heard about was James Nickel's little jewel, *Mathematics: Is God Silent?* Must reading for every Christian math and science teacher, the book introduced me to a serious problem faced by unbelieving scientists and mathematicians. Stated succinctly, the problem is this: mathematics, as a formal system, is an abstraction that resides in human minds. Outside our minds is the world out there, the objectively real world of planets, forests, diamonds, tomatoes, and llamas. The world out there possesses such a deeply structured order that it can be modeled mathematically. So how is it that an abstract system of thought that resides in our minds can be used so successfully to model the behaviors of complex physical systems that reside outside of our minds?

For over a decade now this problem, and the answer to it provided by Christian theology, has been the subject of my lesson on the first day of school in my Advanced Precalculus class. But before jumping to resolving the problem we need to examine this mystery—which is actually threefold—more closely.

In his book, Nickel quotes several prominent scientists and mathematicians on this issue. In 1960, Eugene Wigner, winner of the 1963 Nobel Prize for Physics, wrote an essay entitled "The Unreasonable Effectiveness of Mathematics in the Natural Sciences."[1] Wigner wrote:

> The enormous usefulness of mathematics in the natural sciences is something bordering on the mysterious and . . . there is no rational explanation for it . . . It is not at all natural that "laws of nature" exist, much less that man is able to discern them . . . It is difficult to avoid the impression that a miracle confronts us here . . . The miracle of appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift which we neither understand nor deserve.[2]

Next Nickel quotes Albert Einstein on this subject. Einstein commented:

> You find it surprising that I think of the comprehensibility of the world . . . as a miracle or an eternal mystery. But surely, a priori, one should expect the world to be chaotic, not to be grasped by thought in any way. One might (indeed one should) expect that the world evidence itself as lawful only so far as we grasp it in an orderly fashion. This would be a sort of order like the alphabetical order of words of a language. On the other hand, the kind of order created, for example , by Newton's gravitational theory is of a very different character. Even if the axioms of the theory are posited by man, the success of such a procedure supposes in the objective world a high degree of order which we are in no way entitled to expect a priori.

One more key figure Nickel quotes is mathematician and author Morris Kline:

> Finally, a study of mathematics and its contributions to the sciences exposes a deep question. Mathematics is man-made. The concepts, the broad ideas, the logical standards and methods of reasoning, and the ideals which have been steadfastly pursued for over two thousand years were fashioned by human beings. Yet with this product of his fallible mind man has surveyed spaces too vast for his imagination to encompass; he has predicted and shown how to control radio waves which none of our senses can perceive; and he has discovered particles too small to be seen with the most powerful microscope. Cold symbols and formulas completely at the disposition of man have enabled him to secure a portentous grip on the universe. Some explanation of this marvelous power is called for.

The first aspect of the problem these scientists are getting at is the fascinating fact that the natural world possesses a deep structure or order. And not just any order, *mathematical* order. It is sometimes difficult for people who have not considered this before to get why this is so bizarre. Simply put, the order we see in the cosmos is not what one would expect from a universe that started with a random colossal explosion blowing matter and energy everywhere.

Many commentators have written about this and professed

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bafflement over it. All of the above quotes from Nickel's book and many, many more are included in Morris Kline's important work, *Mathematics: The Loss of Certainty*, which explores this issue at length. In his book *The Mind of God*, Paul Davies, an avowed agnostic, prolific popular writer and physics professor, takes this issue as his starting point. Davies finds the order in the universe to be incontrovertible evidence that there is more "out there" than the mere physical world. There is some kind of transcendent reality that has imbued the creation with its mathematical properties.

The second aspect to the problem or mystery we are exploring is that human beings just happen to have serious powers of mathematical thought. Now, although everyone is happy about this, I rarely find anyone who is shocked by it. Christians hold that we are made in the image of God, which explains our unique abilities such as the use of language, the production of art, the expression of love, self-awareness, and, of course, our ability to think in mathematical terms. Non-Christians don't accept the doctrine of the *imago Dei*, but seem to think that our abilities can all be explained by the theory of natural selection.

But hold on here one minute. Doesn't it seem strange that our colossal powers of mathematical imagination would have evolved by means of a mechanism that presumably helped us survive in a pre-industrial, pre-civilized environment? Our abilities seem to go orders of magnitude beyond what evolution would have granted us for survival.

I know all about the God-of-the-gaps argument, and I'm not going to fall for it here. It may be that some day the theory of common descent by natural selection will be able to explain how we became so smart. That's fine, and I'm not threatened by it. All I'm saying is that for now Darwinism still has a lot of explaining to do. And getting back to the concerns in this essay, I for one do not take Man's amazing intellectual powers for granted. They are wonderful.

The third aspect to our problem is the most provocative of all. Mathematics is a system of symbols and logic that exists inside of our heads, in our minds. But the physical world, with all of its order and structure, is an objective reality that is not inside our heads. So how is it that mathematical structures and equations that we dream up in our heads can correspond so closely to the law-like behavior of the independent physical world? There is simply no reason for there to be any correspondence at all. It's no good saying, "Well, we all evolved together, so that's why our thoughts match the behavior of reality." That doesn't explain anything. Humans are a species confined since Creation to this planet. Why should we be able to determine the orbital rules for planets, the chemical composition of the sun, and the speed of light? I am not the only one amazed by this correspondence. All those Nobel Prize winners are amazed by it too, and they are a lot smarter than I am. This is a conundrum that cannot be dismissed. John Polkinghorne said it well in his *Science and Creation: The Search for Understanding*:

> We are so familiar with the fact that we can understand the world that most of the time we take it for granted. It is what makes science possible. Yet it could have been otherwise. The universe might have been a disorderly chaos rather than an orderly cosmos. Or it might have had a rationality which was inaccessible to us . . . There is a congruence between our minds and the universe, between the rationality experienced within and the rationality observed without. This extends not only to the mathematical articulation of fundamental theory but also to all those tacit acts of judgement, exercised with intuitive skill, which are equally indispensable to the scientific endeavor. (Quoted in Alister McGrath, *The Science of God: An Introduction to Scientific Theology*.)

Which brings us to the striking explanatory power of Christian theology for addressing this mystery. As long as we ponder only

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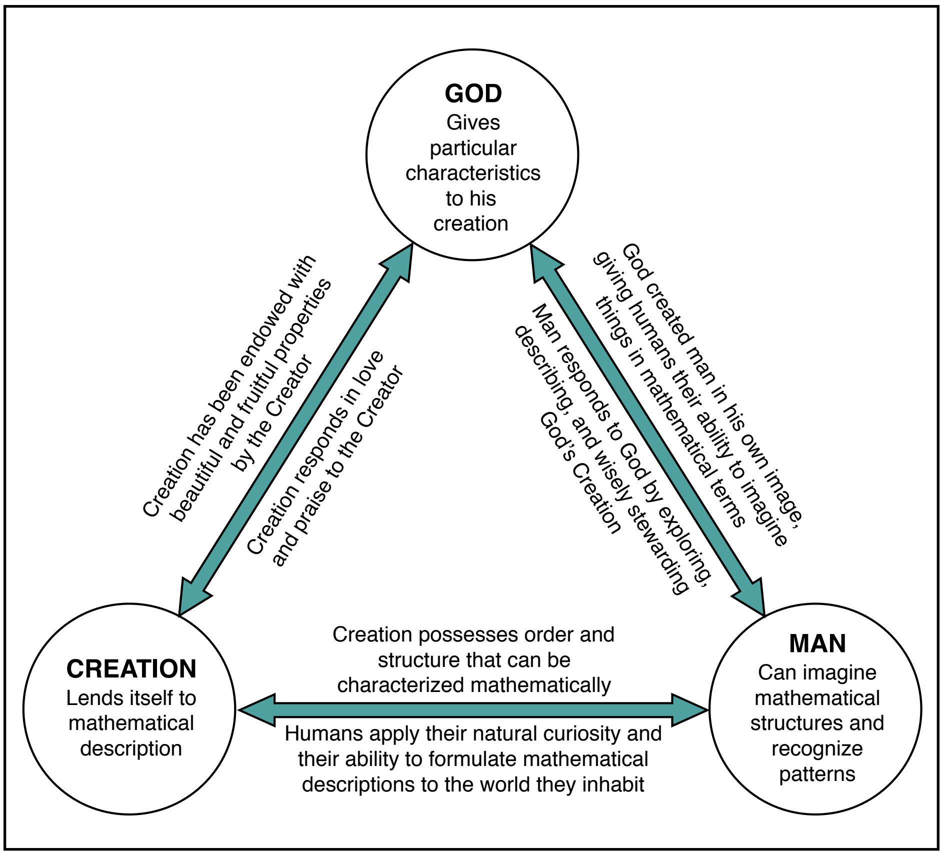
two entities, nature and human beings, there is no resolution to the puzzle. But when we bring in a third entity, the Creator, the God who made all things, the mystery is readily explained. As the figure here indicates, God, the Creation, and Man form a triangle of interaction, each interacting in key ways with the other. God gives (present tense verb intentional) the creation the beautiful, orderly character that lends itself so readily to mathematical description. And we should not fail to note here that the creation *responds*, as Psalm 19 proclaims: "The heavens declare the glory of God." (I have long thought that when the Pharisees told Jesus to silence his disciples at the entry to Jerusalem, and Jesus replied that if they were silent the very stones would cry out, he wasn't speaking hyperbolically. Those stones might have cried out. They were perfectly capable of doing so had they been authorized to. But I digress.)

Similarly, God made Man in His own image so that we have the curiosity and imagination to explore and describe the world He made. We respond by exercising the stewardship over nature God charged us with, as well as by fulfilling the cultural mandate to develop human society to the uttermost, which includes art, literature, history, music, law, mathematics, science, and every other worthy endeavor.



Finally, there is the pair of interactions that gave rise to the initial question of why math works: nature with its properties and human beings with our mathematical imaginations. There is a perfect match here. The universe does *not* possess an order that is inaccessible to us, as Polkinghorne suggests it might have had. It has the kind of order that we can discover, comprehend, and describe. What can we call this but a magnificent gift that defies description?

We should desire that our students would all know about this great correspondence God has set in place, and that considering it would help them grow in their faith and in their ability to defend it. Every student should be acquainted with the Christian account of why math works. I recommend that every math department review their curriculum and augment it where necessary to assure that their students know this story.

The Third Stage in Classical High School Math

by Jim Nance, Logos School

The following is adapted from a speech delivered June 24, 2006, in Covington, Kentucky, at the ACCS annual conference.

The teaching of mathematics in classical schools is informed by our understanding of the Trivium. The goal of classical education is to give students tools of learning, tools which they can use to learn on their own at their different levels. These tools are different at different stages in the child's development: the grammar stage, the dialectic stage and the rhetoric stage. Students acquire tools in every stage. In Dorothy Sayers' essay "The Lost Tools of Learning," she calls the grammar stage the "poll-parrot" stage. In the stage before that, the students have learned how to "read, write and cipher" (the pre-polly stage as Tom Garfield calls it). The grammar stage really starts about third grade and goes on to about sixth grade.

In this stage, Sayers writes, "Anything and everything that can be usefully committed to memory should be memorized at this period, whether it is immediately intelligible or not. The modern tendency is to try to force rational explanation on a child's mind at too early an age. Intelligent questions spontaneously asked should, of course, receive an immediate and rational answer. But it's a great mistake to suppose that a child cannot readily enjoy and remember things that are beyond their power to analyze."

I hope this isn't too radical to say: I believe Dorothy Sayers at this point; I think she is right. The sort of things that should be memorized at this stage, the grammar stage, would include: the multiplication table (we do it up to 12); the long division rubric (how you divide long hand), the names of all the basic shapes (hexagons, right angles and trapezoids—that sort of thing), names of basic number groups, real numbers as distinguished from integers, positives and negatives, whole numbers, natural numbers, basic fractions and their decimal equivalents. What is the decimal equivalent of 7/8? Students should know it is 0.875 without having to think about it, and so on. Anything that can be readily memorized and stored in the mind should be memorized at that point, so that it can be quickly and accurately recalled and used at later stages.

Students should memorize some things that they are not able to analyze, and by that I mean the students need not necessarily explain *how* they work or *why* they work, just *that* they work. For example, it is perfectly acceptable for a student to be able to do a long division problem without being able to defend the long division rubric. Can *you* defend the long division rubric? We should expect them to know it, and know it well. But let them wait until high school before they have to defend how it works, to be able to justify it in a logical way. The long division rubric is a typical tool of learning at the grammar stage. Keep in mind that a tool of learning is the tool that allows the students to teach themselves. Students could use this tool to teach themselves that 7/8 is 0.875 as a decimal. That's a fact that they can learn by using the tool.

At the grammar stage, the teacher should be the expert, telling the students correct answers and proper procedures. But if the students ask why, the teacher should be able to give a rational explanation. If a student asks, "Why do we 'carry' in the addition of large numbers?" the teacher should be able to give a rational and correct answer. Or they might ask, "Why do we shift the product to the left in the next row down when we are doing a long multiplication problem?" The teacher should be able to give a rational explanation. That may or may not be something that students in the grammar stage can understand and appreciate. If they do understand and appreciate it, they will more readily remember how to do it.

In short, grammar stage students should learn arithmetic. Arithmetic lines up well with what Sayers teaches about that stage. Anything that they can memorize should be memorized so that these memorized facts and procedures, which flow from the concepts, can be easily and automatically recalled by the students for use in the next stages and for the rest of their lives.

The dialectic stage, also called the logic stage or the "pert" stage, corresponds roughly to junior high or middle school. Math properly includes algebra and geometry in the junior high classes, seventh and eighth grade. At this stage, the students improve in their abstract

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reasoning skills, and their study of mathematics should reflect that.

Notice that I don't say that at this stage students begin to reason abstractly. That's not true. They already reason abstractly by the time they are in school. Any student that can understand the number 12 as an abstraction, apart from twelve things—like 12 eggs or 12 elephants—is able to think abstractly. Arithmetic deals with that first level of abstraction. At this level, students can multiply 12 x 9 and get 108 without having to think about what that number means.

But algebra brings students to the next level of abstraction. With algebra we now have a letter representing a number representing a number of things. Algebra is two levels of abstraction deep. The ability to think mathematically at this second level is what begins to develop at the pert stage and sets this apart from other mathematics. So in algebra, we manipulate letters as numbers following certain logical laws. For example, algebra students learn to factor $x^2 - y^2$ into $(x + y)(x – y)$. They do not have to think that this means $5^2 - 3^2 = (5 + 3)(5 – 3)$, or that 5 is five eggs and the 3 is 3 eggs. They are beyond that.

We are dealing with that second level of abstraction in mathematics at the dialectic stage. Logic students are at the same level. In a formal logic class, variables represent words which represent things, or variables represent propositions which represent ideas. That is why logic, algebra, and geometry line up so well, all being taught around the same time.

The pert stage student often begins to desire to prove things at this time. So in algebra they begin to prove theorems and to derive equations. Understanding a mathematical procedure is more enjoyable for them at this time, rather than just being told what it is. They enjoy being able to prove it, or at least see how it is proven. Students should learn classic geometry which really focuses on proofs, along with compass and straight edge constructions. These problems teach the sort of precise reasoning that students at this age need to learn.

But what about the rhetoric stage? For years, I have read and re-read Dorothy Sayers' article and asked myself: How does my teaching of mathematics reflect what she says about the poetic stage?

I distinctly remember enjoying proofs when I was a geometry student in ninth grade. I remember in eighth grade looking at what the ninth graders were doing and saying, "I want to be able to do that! I can't wait until geometry next year!" And then I couldn't wait until trigonometry, and then I couldn't wait until calculus! It was all exciting because it lined up well with where I was as a student.

Teaching at the pert stage should include more Socratic discussion. Teachers should be asking questions of the students, leading them in discussion to deduce the conclusions—often the point of the lesson—that the teacher has in mind. If you want your students to develop their reasoning skills, you need to make them do the reasoning.

You should see that classical math, the math that most of us learned in school, follows the pattern of the Trivium fairly well up until this point. Learning arithmetic, which almost all schools do and should continue to do, lines up well with the grammar stage. Learning algebra and geometry lines up well with the dialectic stage. As long as we continue to do this, we are following the classical model at these stages.

But what about the rhetoric stage? For years, I have read and re-read Dorothy Sayers' article and asked myself: How does my teaching of mathematics reflect what she says about the poetic stage? How can our understanding of the Trivium inform our teaching of high school mathematics? In "The Lost Tools of Learning," Sayers identifies the master faculties of the grammar stage, and the master faculties of the pert stage, but neglects to identify the master faculties of the poetic stage. For the grammar stage they are observation and memory; for the dialectic stage it is discursive reasoning. So what is it at the poetic stage? In describing what the students of the medieval Trivium learned, Sayers writes, "Thirdly, he learned to express himself in language: how to say what he had to say eloquently and persuasively." That is the first master faculty of the poetic stage: expression—expressing yourself eloquently and persuasively.

Later, Sayers writes, "The doors of the storehouse of knowledge [at this third stage] should now be thrown open for them to browse

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about as they will. The things once learned by rote will now be seen in new contexts; the things once coldly analyzed can now be brought together to form a new synthesis; here and there a sudden insight will bring about the most exciting of all discoveries: the realization that truism is true."

At this stage then, students are synthesizing the things they learned in the grammar stage and the dialectic stage. Things once learned by rote in the grammar stage are now seen in new context. Things which were coldly analyzed in the dialectic stage are now brought together to form a new synthesis. Students at the third stage should be "expressing themselves," "browsing about as they will," "making exciting discoveries." Those are the sort of words that Sayers is using to describe this stage, so if she is right then this should describe to some extent our study of mathematics at this stage. Well, *how?*

At this stage especially, math teachers need to teach in such a way that the students can discover problem-solving methods for themselves and learn to express their discoveries clearly and completely to fellow students. Remember, we are trying to give our students the tools of learning. They won't always be in the classroom, but hopefully they will be lifetime learners. How do you learn on your own? We need to lead them into that in high school.

How, in math at this stage, are things that were once coldly analyzed now "brought together to form a new synthesis"? Let's look at the idea of synthesis first. Analytical geometry is a synthesis by its very nature. Also called advanced algebra, it is really a synthesis of two subjects once "coldly" analyzed: algebra and geometry. Analytical geometry takes the equations of algebra and shows how they can be used to form and analyze the shapes of geometry. Descartes introduced this idea—this radical idea—that algebra and geometry are not two separate maths, they really can be brought together into one new (and more powerful) system; they can be synthesized.

This, by the way, is why advanced algebra is properly taught after algebra and geometry. People have asked me, "Why do you teach algebra, then geometry, then advanced algebra? Why do you have that year of geometry separating the two?" Because advanced algebra is analytical geometry. You need to see the two subjects separately first, and then you can see how they synthesize and come together. It is perfectly appropriate to follow that approach: algebra, geometry, advanced algebra.

Trigonometry continues that synthesis. In trigonometry, we now see angles (things of geometry) being studied by means of equations (things of algebra). It's a synthesis of geometry and algebra, working especially with angles.

Calculus, as I regularly tell my calculus students, requires them to bring together everything that they have learned in all their previous math classes. You need to remember the double angle identities, you need to remember what a function is, you need to remember how to complete the square. All of those lessons that you learned before need to be recalled and used in calculus.

At this stage especially, math teachers need to teach in such a way that the students can discover problem-solving methods for themselves and learn to express their discoveries clearly and completely to fellow students.

How should we teach math so that students are synthesizing all of their learning, making their own discoveries, and expressing these discoveries with elegance and persuasion? Here is my proposed script for a typical lesson in high school mathematics.

First, start the day's lesson by giving the students a challenging problem to solve—a problem which makes them think, not one that they immediately know how to solve without thinking. It is your job as a high school math teacher to find that middle ground, to find the appropriate problem that they can reach for and grasp by exerting their own mental energies. Bring them a problem that is over their heads, that they can reach if they reach up, but not something that is so far up that they cannot reach it no matter how hard they try, and not something that is already at their level that they gain nothing by solving.

Such a problem should be solvable by a student who understands the basic concepts of mathematics, who really has learned what they are supposed to have learned up to that point, and who remembers the facts and procedures taught in previous math lessons. We want

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to develop the sort of student who remembers previous lessons and has the creativity to bring those lessons together.

With some lessons, after presenting the problem, the teacher should lead a guided discussion to help the students, working as a whole class, to develop a problem-solving method. If the lesson is entirely new, and it is a new foundational idea, and it is the first time they have been presented with it, then I think this is a proper method for using in high school.

So imagine that this is the first time you are teaching students about the slope of a line. You should use a guided discussion to lead the students to understand what the slope of a line is. You can start the discussion by drawing different lines. You then say, "What characteristics distinguish these lines from each other?" There really are only two characteristics: where they intersect one of the axes, and how steep they are. Then you say, "Let's talk about how steep they are. That's called the slope of the line."

The typical procedure would be to say, "We're going to talk about slopes today. The slope is how steep a line is," and so on. I'm saying that we should go the other way: let the students tell you that what distinguishes one line from another is how steep it is, how fast it goes up (or whatever their language is). Then teach them that the word being used to describe the idea is "slope." Then ask, "How can we use numbers to tell how much that slope is? How can we use numbers to describe that?" The students will probably say, "Well . . . I don't know!" You could say, "Okay, let's talk about stair steps. Imagine you put stair steps under there, like placing a flat board on top of the stairs. Think about how wide and how tall the steps are. Now, tell me how you might use numbers to describe how steep that board is." You can ask them questions and eke it out of them until they eventually say, "The slope is rise over run, the change in y over the change in x." That's a basic example of getting the students to discover the conclusions you want them to discover, not telling them first, but educating them by educating their thinking process.

. . . when a lesson builds upon some foundational concept that is already familiar to the students, like most of our lessons do, then the teacher should allow the students to work together, to invent and discover a problem-solving method on their own.

But when a lesson builds upon some foundational concept that is already familiar to the students, like most of our lessons do, then the teacher should allow the students to work together, to invent and discover a problem-solving method on their own. Having presented a new problem for the day that they do not initially know how to solve, put your students together into small groups of three to five (depending on the size of the class), and give them five to twenty minutes (depending on the difficulty) to work together to come up with a method of solving the problem. The teacher should go from group to group as the students work. His job is not to tell them how to solve the problem. His job is to give them hints and suggestions to move them in the right direction until they discover how to solve it on their own.

Let the students struggle with the problem, but encourage them. "Keep thinking; you're getting close! You're getting an idea of how to do this!" And let them know that the solution is within their grasp; encourage them as God encourages us. As a teacher, do not think of the students' struggle, confusion, and error as a problem to be fixed by you; instead, look at the students' confusion and struggle and error as an opportunity for them to learn that they can overcome those difficulties with their own unaided effort.

Remember, the goal as classical educators is to teach students how to teach themselves, how to learn on their own, independent of a teacher being present. That is how they're going to be learning in a few years anyway, in college, and then beyond as they become lifelong learners.

However, let me modify this a bit. It's sometimes a good idea not to put the students working together in groups immediately upon presenting them with the problem. Instead, give them a few minutes to try to solve the problem independently at their seats. Give them a problem and say, "Think about this problem for a little while and be working on it." Then go up and down the rows watching as the students work independently. This benefits the class in two ways: it gets students thinking individually, and it gives them some place to

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start when they do get together in groups. One of the students will say, "This is what I came up with" and another will say, "That's what I came up with." "Okay, let's run with it!" It gives them a foundation to work from.

Now, consider varying how you do that—sometimes make them work longer individually. That way the more reticent students do not learn to just wait until they get together in groups so that they can let Bill the Math Wiz figure out how to do the problem. Go ahead and let them work individually longer. Sometimes put them into groups right away. Vary how you do it to surprise the students and keep them on their toes.

You've presented the problem, you've let them work together for a couple of minutes on their own, you've put them into groups. Now the students, in their groups, have begun to solve the problem correctly—you've got this group and they've figured out one method, and you've got another group and they've figured out a different method. Next, you should select students from each group and have them write their solutions on the board. Sometimes do this with several students at the same time, and sometimes choose a group that does not yet have the answer. They may go up front and say, "This is what we came up with so far, but we are stuck at this point." Then let the rest of the class help them think through it.

Or sometimes, let one student who can solve the problem go up front and teach the class. We want the students to be learning on their own and to be able to express themselves eloquently and persuasively. That's what the poetic stage is all about. In this method, students are doing the mathematical thinking, struggling, and discovering, but they are also learning how to express their thoughts clearly to others.

Finally, the teacher should end the lesson by summarizing what they have learned, either the teacher himself doing the summarizing, or the teacher asking the students to summarize what they have learned. What method, or what technique, did you use? How does that technique flow from the basic concepts? How does it relate to other concepts? Spend a few minutes summarizing it, bringing it all together into a clear new tool that they discovered and that they can then use.

After the lesson is finished, the students should be given problems to work on. This verifies that each student is learning, rather than just resting on the work of some fellow student.

I usually do not assign a lot of homework problems. Rather, it is my goal that the good students are able to finish that day's problems in class. I want a large percentage of my class to be able to finish within the period and have no homework in mathematics. Let me repeat: the best students should typically have little or no mathematics homework. Some slower students would regularly have math homework, of course, but my goal is that the good math student will have no homework.

Let me put some feet on this. Let's run through a typical lesson and show how many minutes each part of the lesson takes.

The class bell rings. The students in our school stand next to their desks, then I tell them to please be seated. I greet them and take attendance. That typically takes about one minute.

Then I read answers or I call on students to give answers from the previous day's assignments. That takes about five minutes. It could be longer if there was a question that most of the students had trouble with, or it might be shorter.

Then I present my new problem for the day (two or three minutes). Often, I have the new problem written on the board before my class even starts. The students look up there and say, "Oh, that's what we're going to be trying to figure out today." That piques their curiosity. Where do I get that problem? I don't usually make it up myself. I choose some sample problem in the text, or I choose one of the odd-numbered problems, which have the answers in the back of the book. I choose these because I usually assign even-numbered problems for the classwork, problems that they don't have the answers for so they are required to figure out how to solve them on their own.

The students then work individually at their desks to try to solve the problem, and I answer some preliminary questions. I wander from desk to desk to make sure that they understand exactly what the problem is asking. I am not doing this to tell them how to solve it; I am doing this to make sure they understand what the problem is. That takes about three minutes or so.

Then I say, "You've worked independently and some of you are starting to get it. Now, you three form a group over there, and you four form a group there, and you four a group over there. Work together to try to figure out how to solve this particular problem." And then I wander from group to group, offering hints and suggestions. I might say, "That's a good idea there," or "you need to look at what you've done here," or

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"you've made some mistake there, try to find it." If I'm asked a direct question, I usually try to answer with another question. Again, I want to keep them thinking. But I do not frustrate the students to the point where they do not like it. So sometimes I will answer a direct question with a direct answer. This method follows one of the seven laws of teaching: "Never tell a student something that he can figure out on his own." This group work typically takes about 15 minutes, give or take five minutes.

As the groups begin to figure out the answer, I typically will choose a student who understands the solution and have him explain on the board how he has solved the problem. Then we'll discuss it as a class. With the student up front I'll ask, "As you work the problem out on the board, tell your classmates what you are doing." The student becomes the teacher, being the one who has figured it out and explains it to the class. Then, I'll usually have a student summarize the main point, so that the students, having worked together, now present it to the rest of the class. This usually takes about ten minutes.

Finally, I assign problems for the students to work on which apply or extend that day's lesson. That covers the remainder of the period. I usually have about twenty minutes left in class by this time. That is my typical outline for a lesson.

There are some difficulties to overcome. Teaching is a cultural activity, and students who first encounter this method will be surprised. "What? You're not going to tell me how to solve this problem?" "No, *you* are going to figure it out." Some of them may be initially resistant. My suggestion here is to persevere.

Coordinate with other high school math teachers. In order to make this work, you will need to work together with your fellow teachers. The earlier classes can be used to prepare the students for what they are going to be facing in high school. Ideally, in geometry, the best place to present this sort of approach is with proofs. Give the students a proof that you have not shown them how to solve, let them work individually on the proof for a little while, and then put them into groups. Follow this procedure with that particular part of geometry. And then the next year when they are using this method even more, they'll think, "Oh, this is how we did proofs. We're just doing it now for most lessons."

I firmly believe that this follows the classical approach to teaching math at the high school level. It requires more work on the students' part, and by work I mean more thought. Thinking is hard work. But as they become accustomed to it, they learn to enjoy the idea of discovery. "I found this out on my own! I figured out how to solve this!" And solutions that they find on their own, they never forget.

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