MATHEMATIC MODELING FOR THE LIBERAL ARTS: GRAPHIC LITERACY

Dian Calkins

Department of Natural Sciences and Mathematics
Dominican University of California,
50 Acacia Ave. San Rafael CA 94949 USA
Email: dcalkins@dominican.edu

Sibdas Ghosh

Department of Natural Sciences and Mathematics
Dominican University of California
50 Acacia Ave. San Rafael CA 94949 USA

Abstract
Mathematics is traditionally linked with programs in the sciences, as a language for understanding the natural world and for solving quantifiable problems. For Liberal Arts students the great value of mathematics lies not in calculation or formulas, but in development of what researchers call "mathematic intuition."
This is the ability to puzzle out meaning from data, to recognize how information might relate, to gain a perspective, to build valid conclusions from numeric information and to innovate based on the patterns discovered.
A good way to build mathematic intuition is through modeling. Creating visual models such as graphs, diagrams, maps, codes and networks gives shape and meaning to what students learn.
After graduation, Liberal Arts students will use modeling skills and mathematic intuition to explain their ideas and progress to their colleagues and to us; it is how they will enlarge the impact their knowledge and their chosen fields will have on solving world problems.
Development of mathematic intuition is a primary goal of Liberal Arts mathematics, and one of the hallmarks of a Liberal Arts education.

Key words: Liberal Arts students, mathematic intuition, visual models of quantitative information
MATHEMATIC MODELING FOR THE LIBERAL ARTS: GRAPHIC LITERACY

A comedian who began his career in San Francisco in the 1970’s once proposed a novel approach to undergraduate education called “The 5-minute University.” The program proposes an accelerated course of study, in which students learn in 5 minutes the knowledge equivalent to what a typical student remembers 5 years after graduation. In economics, the course is “Supply and Demand.” That’s not the title of the course; that is the entire course. The English Literature course is “To Be, or Not To Be.”

The 5 Minute University raises several questions about the traditional math requirement for students of the Liberal Arts. First, what will the students remember 5 years after graduation? Cramer’s Rule, Gaussian Elimination, how to find a linear regression? Likely, none of these calculations would be remembered. Thus there would be no math class for Liberal Arts students in the 5-minute University.

But there is one at our university, and for those students of history and psychology there are more questions: Is learning to calculate using formulas the ultimate goal of their math course? What should be their personal advantage from the math they learn—and what is the added value to their undergraduate program from the way they learn it?

Brain research at the Mass Institute of Technology indicates that different ways of processing mathematic information use different parts of the brain. Proscribed numerical calculations such as those listed above, engage the same part of the brain that is active during verbal memorization. This memorized mathematics is being called an “empirical knowledge of mathematics.”

This is represented by the ability to recall formulas, to successfully recapitulate a numeric process and to follow sample procedures using alternative variables. A large store of empirical knowledge in mathematics, or any topic, can be built using memorization. Considering mathematics to be basically a manipulation of numbers might be like considering music to be a manipulation of notes. The advantage of working mathematically does not lie here.

Brain imaging shows that a distinctly different part of the brain is used when students puzzle out and form conclusions from mathematical information. Designing a way to represent information mathematically, learning to recognize how quantitative information might relate, and the creation of new personal understanding, are skills that seem to be tied to a spatial relations tool researchers call “number sense.”

Number sense may be the key to building a sensibility called “mathematic intuition.” I believe the life-long value of mathematics, for students in every discipline, is the development of number sense and mathematic intuition.

A very direct and effective way to build mathematic intuition is to create visual models: single or multiple-dimension abstractions that represent reality, such as graphs, diagrams, maps, codes, and networks. The immediate goal of modeling may be to clarify or help solve a problem, but the higher goal is the ability to create abstract structures through which an individual can acquire a perspective or understanding of the world not readily apparent in other forms. Gaining that perspective or understanding is a primary goal of mathematics—and one of the hallmarks of a Liberal Arts education.

Math in this form is a laboratory discipline: students sort and validate information; they write translations between graphic and literal descriptions; they recognize components in the problem that change (variables) and that do not change (parameters); and they design models that depict valid relationships in information (functional forms.)

There are 3 very practical reasons for learning to read and create models.

First, modeling is an analytic skill used to reflect on information of any kind; it is a tool to extend farther into any field; it is a communication device students will use to explain ideas and progress to their colleagues and to us; and it is how they enlarge the impact their knowledge and their field will have on solving problems. It is how to understand what you find, and how to design your strategy to move ahead. It is both the wind and the sail.

Second, modeling sharpens number sense: it reveals the shape of information and the anatomy of our thoughts. We use models to clarify a position, chart our progress, trace our reasoning, identify our priorities and even form our values. Modeling can bring insight; and it can make the familiar look new.

Also, scientific advancements often mark the intellectual climate of an era, and citizens who lack the mathematic intuition needed for basic understanding can be cut off from the intellectual tenor of their times much the same as a person who cannot read.
There are also 3 philosophical reasons.

As we confront the mysteries of the world we discover a matrix of pattern and process; we stand at the edge of what we know, looking out into what we don’t know. Mathematic Intuition enables us to conceptualize- to give shape and meaning to what we know- and to hypothesize about and gain ground into what we don’t know. We link new information, construct a more complete understanding, and move a little deeper into unknown parts of the world matrix.

In every field, the Prime Directive is: “Contribute to what is Known.” Mathematic Intuition is the foundation of every unique contribution—not just in science but human endeavor as diverse as business projections and interpretive dance.

Liberal Arts are traditionally the background of our future leaders. But all citizens must be prepared to help solve public issues that require mathematic sensibility, in order to more responsibly participate in keeping the democratic process alive.

1.1 MODELS INTENSITY OUR UNDERSTANDING

Maps and charts have served to clarify events through all phases of human history. Following is a collection of models that have recorded and influenced history. As students learn to find patterns in information represented spatially, they develop numeric insight; they learn to recognize and trace motion and process, to read balance and symmetry, to link information with valid connections, to translate numeric information literally and finally to build mathematic intuition by creating models of quantitative information.

Students in the Liberal Arts math course also become familiar with the ancient roots of modeling; the oldest artifacts exhibiting mathematical structure. 25,000 years ago on the shore of a lake bordering Uganda and Zaire, someone clearly marked numeric patterns on what is today called the “Ishango Bone.” Marks scratched into the surface clearly, amazingly, attest to ancient humans’ mathematic sensibility.

The scratches in rows (a) and (b) each add to 60. Row (b) contains the prime numbers between 20 and 10. The numbers in row (a) can be characterized as “20 + 1” “20 – 1” “10+ 1” and “10 – 1.”

Row (c) shows evidence of duplication, or multiplication by 2. Once students have investigated the patterns it may be possible to hypothesize about the purpose or meaning of the marks. Quartz shards at one end may have been for marking; perhaps this bone was a tool handle.

Under microscopic study, the bone reveals additional marks that indicate it is a lunar phase calendar.

Mapping is also a very old skill- cartography existed long before written language. This beautiful map found on the site of the ancient city Catal Huyuk in Turkey is carbon dated to approximately 6200 BC. It is approximately 9 feet long, and is believed to show 80 buildings in the town.
plan of Catal Huyuk. The volcano Hasan Dag lies close to the city and is shown erupting.

What does the map possibly reveal? What can students propose about this city? Students learn to find the essential truths depicted and to translate them into other modes such as drawings, models or diagrams. Representing truth in various forms is a fundamental aspect of literary, performance and graphic arts, through the ages.

Studies at the site have generated several graphic and physical reconstructions of homes and community. This drawing, like the original map, shows no streets; all houses were linked together. The city's inhabitants walked on rooftop paths and dwellings were entered through the roof.

Sticks, bones, shells and rocks all carry the evidence of early humans' mathematic sensibility.

This geometrical diagram illustrating the Pythagorean theorem is from the Old Babylonian Period 2000 BC, long before the time of Pythagoras. Babylonian scribes knew the length of the diagonal of a square is equal to the length of a side multiplied by the square root of 2. Along one diagonal is written the length in the Babylonian base 60 system. One side is labeled with its length, and the product of this number and the root of 2 is also written along the diagonal.

One of the earliest line graphs we have found is this from the 10th century showing movement of sun, moon and planets in space and time. On the Y axis, marked from the top, are Venus, Mercury, Saturn, Sol, mars, Jupiter, and Luna. What components does the graph lack?
1.2 THE ART OF GRAPHING

One of the giants in the history of graphic creation is William Playfair, an 18th century political economist. His graphs are so clear and beautiful they are now considered works of art. His topics included history, social issues, commerce and taxation, and all his designs are engaging and easy to read with graduated and labeled axes, grid lines, labels written along the graphed lines, a clear title, and hand coloring for each category. Studying famous Playfair graphs is an entire course in itself.

This Playfair model illustrates the English prime minister’s idea for a “Sinking Fund” which would reduce the national debt. Each year 1 Million pounds of the surplus revenue raised by taxes would be added to the fund. The interest on the fund would be used to lower the national debt.

With clarity and high impact, Playfair illustrated the excessive taxation of the people of Britain in the early 19th century. Each circle is a separate country. The red lines to the left represent population and the yellow line on the right indicates the tax revenue. The dotted line connectors keep the two lines for each country visually connected. The slope of each set of connectors shows tax revenue in proportion to the population. Not only is Britain collecting a very high total, it is startlingly disproportionate to the number of payers.

Nowhere is change over time more apparent than in the famous graph by Charles Joseph Minard recounting Napoleon’s disastrous invasion of Russia in 1812. It is a more complex graph but ingeniously designed and a valuable addition to a graphing course. At the left is the Polish-Russian border. The upper tan line traces the route; the width of the line depicts the size of Napoleon’s army as it moved east to attack. The black line represents the same army during the withdrawal from Moscow back to Poland. There are minor problems with the graph, but the brilliant use of the thinning line as the dominant characteristic clearly shows the tragic attrition of the French forces. The technique lends itself to student projects such as tracing the diminishing polar ice cap, the population increase of an environmentally protected species, the rise of social networking for a target age group, or the number of school-age children considered overweight.

In 1853, Russia fought against an alliance of European countries in the Turkish region known as the Crimea. The Englishwoman Florence Nightingale volunteered as a nurse, working in hospitals with almost no equipment.
no medical records, and no sanitation; rats and fleas were everywhere. She kept records and devised many graphic methods for displaying the data. The most famous of her graphs is known as the "Polar Area Graph" that she labeled "The Causes of Mortality in the Army in the East."

The twelve sections represent the months in a year. The area of a section measured from the center, indicates the number of soldiers who died in that month from a specific cause.

She colored red the areas that represent deaths due to wounds; blue areas represent deaths due to preventable causes, and black areas represent deaths due to all other causes. Many more soldiers were dying from preventable causes than were dying in battle! The impact of her graph on the British government is credited with saving many lives. Polar graphs separate multiple components and can help focus a discussion.

Why was the campus voter turnout so low? How is available space in the newspaper allotted? What forms of communication are most prevalent among students during the week?

In 1854 a plague of cholera swept through London killing 10% of the population. London was a very dirty city, with no effective sewage system. Dr John Snow investigated one specific neighborhood and became convinced the pattern on the map he devised showed the disease was probably spread not through the air as was commonly believed but through contaminated drinking water.

The dark bars on the map represent the number of deaths that occurred at each address. Dr Snow noted the geographic concentration in the vicinity of the water pump at 40 Broad St.

To test the hypothesis that the neighborhood water supply was the original source of the plague, Dr. Snow needed to determine the distance from each affected household to the Broad St. pump, as compared to the distance to other local pumps.


Fig 15: John Snow’s map. Retrieved from http://www.ph.ucla.edu/epi/snow/snowmap1_1854_lge.htm

The curve on his map connects the points from which the Broad St pump is equidistant from other neighborhood pumps. For people living inside this curve, the Broad St pump was the closest source of water. Dr. Snow had the handle of the pump removed, and the cholera outbreak dissipated.

Today, this memorial to John Snow—a water pump with no handle—marks the location of the old Broad St. water pump. In 2010, the devastating impact of cholera came to the small Caribbean island nation of Haiti. 485,000 cases studied by the World Health Organization and the United States Centers for Disease Control and Prevention have generated at least two hypotheses for the origin of the outbreak. Possibly it was brought to Haiti by outside persons and spread through direct contact or water; possibly the toxin in the cholera bacterium lies dormant in costal water, until changes in temperature and salinity activate the microbes.

Conclusive scientific evidence for the origin of the epidemic has not been established. It is a goal worthy of investigation by the mathematic modeling technique originating with Dr. John Snow and now known as medical cartography.

The connecting line device used by Dr. Snow is now called a voronoi diagram, and today it is widely used to study division of space in problems of competition such as territory between animal species, or the range and overlap of economic markets. This diagram technique is an analytic tool used by anthropologists determining regions of cultural influence, by city planners to find the best location for a new park or university branch, by photographers to create a mosaic effect on an image, by event managers designing a site, and by naturalists studying the rise and fall of the honeybee population or how ferns fight for space on the forest floor. Students of very disparate interests can find, explain and create good examples from their own field.

This voronoi diagram was designed by Rene Descartes in 1644. There exists no authentic numeric description of the information contained in this map. Students may be able to write individual or group interpretations.
1.3 Modeling Our World

The spacecraft Pioneer 10, launched in 1972, traveled through the Asteroid belt, took close-up pictures of Jupiter, and then left the Solar system. It is now headed toward the constellation Taurus, with a trajectory that would cause it to pass Aldebaran, the nearest star in that constellation, in about 2 million years. For any sentient life it encounters en route, it carries a picture-diagram describing the origin of the spacecraft, the form of the beings that sent it, and the location of the world they inhabit. As students study this code they may consider other units of measure that could be used or alternative information to include.

1. The image of the man and woman, demonstrating the human life form. The figures are not holding hands as originally designed, lest the viewer mistake the drawing for a single creature rather than two separate life forms.

2. The outline of the Pioneer spacecraft shown behind the human forms is in the same scale as the figures, so that the size of the creatures can be estimated by measuring the spacecraft.

3. The sun-centered solar system

4. A picture of the Pioneer space probe at the end of a line emanating from the third planet indicating where the message comes from

5. Binary numbers, a vertical line for 1 and a horizontal line for 0, on planets indicate relative distance from the Sun. The unit of measure is equal to 1/10 Mercury’s orbit.

6. The star map locates the Sun. The radial lines locate pulsars, stars emitting a regular electromagnetic pulse, with a binary number indicating frequency

7. Hydrogen atom, represented by a circle, is the unit of measurement of time and distance. When the orbiting electron flips states it emits a photon that constitutes a universal measure of length (21 cm) and time (1420 MHz)

8. The image of the Pioneer space probe compares the height of humans compared to the probe.

9. The height of the woman is in binary: 1,000 units of length. The unit of length—the length of pulsar wave when hydrogen transitions is 21 cm. As 1,000 is eight in binary, the woman’s height is 8x21 cm = 168 cm.

In the summer of 2005, rangers in Yosemite National Park began an effort to collect and contain a species of large frog that had overrun its environment. They shared with my students data from some July nights when the catching was especially good.

This is a sample of the data we received.

The rangers’ data tells much about the frog population as they looked for patterns and relationships between location and size of frog caught, time of night and size of frog, total number of frogs caught during equal time span at each site, and comparison of sex of frog to size of frog. Students can write literally about the findings, justifying answers to sample questions which was more successful, evening catching or late-night catching, if the goal was to catch the most frogs? What if rangers were trying to capture the largest frogs,

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Fig. 20: Pioneer Plaque: Diagrams that changed the world. Retrieved from http://www.bbc.co.uk/news/magazine-11798317

Fig. 21: Catching Frogs in Yosemite National Park Rachowicz, Lara J. (2006) Aquatic Ecologist Resources Management and Science Yosemite National Park El Portal, California USA
or just the females? This data came with a hypothesis from a ranger who suspected that after one night of catching, in any given location, the frogs were wise to them and were not as easily captured the following night. She advised waiting 3 more nights before revisiting the same location. Does the data support this theory? Designing a graph to show this information would be a good student activity.

Another useful way to illustrate pattern and change is with a Tree Diagram. Vertex points and vectors show sequence of connections, common origins and branching. The design is simple and can illustrate very complex processes.

All the information a gene carries is encoded by the sequence of the bases scientists label A, C, G and T. Mutation occurs when the sequence becomes changed. This chart illustrates a single gene that has become mutated to A, B and C. The distance between any two leaves is the number of positions that differ in the sequence. From A to B is a distance of 2; from A to C is a distance of 3.

A chart of possible distances between leaves, or mutated cells, is called a distance matrix. This type of diagram can help clarify what life forms evolved from what others, and the distance component can help determine when.

Students can draw this type model to illustrate distance or degrees of separation in diverse structures such as food production and distribution, fair governance, accessibility of health care services, lines of communication, and transportation networks.

For students of the arts, materials and venues such as canvas and paint, drawing implements, building materials or photography blend easily into a modeling course. The introduction of visual, performance, constructual or other forms of artistic expression also opens an opportunity for students in other departments, that is not found in every Liberal Arts program. The interconnected nature of art, music, physics and mathematics becomes apparent.

In 1889 Gustav Eiffel incorporated interwoven girders supported by a lattice of smaller trusses and beams into the design for his tower, incorporating the mathematic tenet of self-similarity, to efficiently use materials and minimize weight. Fractal mathematics are fundamental to the structure of Impressionism, Cubism and Modernism, ragtime and jazz, as well as architecture.

1.4 MODELING IN THE AGE OF TECHNOLOGY

With the astounding power of technology to reveal visual patterns, modeling has morphed—branched into new languages, expanded to new capabilities. We now model information that was until very recently completely unknown.

Models respond to adaptation, allow changes of perspective, and facilitate fine-tuning into the interior or into the future, even far past our imagination.

Mathematic models make the invisible, visible. Access to modeling software allows instructors and students to cooperatively study, design and create models in a classroom that becomes a laboratory.

Myoglobin is an oxygen-binding protein. It is found mainly in muscle tissue where it...
serves as a storage site for oxygen. If deprivation of oxygen is sensed, it releases its bound oxygen into the body. The artist Irv Geis painted biomolecular art, which he called portraits of molecules. It is startling to see so clearly the beauty of the mathematics within life.

One of the single most famous symbols representing science and mathematics is a photograph. Notice the expression, the posture, even the clothes: Does the image tell you something intuitively about Albert Einstein that a biographical abstract would not? Photographs as models can be designed and read for nuance, subtlety and detail, or for overview of huge information. Studying many kinds of photographs will help students learn how photos convey Information.

A Maximum Wave Amplitude Model. This helps us consider how vast is the affected area on the earth; the awesome force modeled here has a progression impact not as apparent in a list of data. After deciding on a usable scale and limit, students can create a color-coded diagram or physical map of motion and strength, motion and concentration, or motion and change in speed.
Thread scheduling is the process of diagramming routes and data flow. Route maps can help students study communications, health and medical outreach, the timeline of product development and distribution of goods and services.

The initial process t₀ creates thread t₁ and thread t₂. Then as t₁ moves to t₃ and t₂ moves to t₅, thread t₀ moves to t₆. At time 3, thread t₀ goes on (through t₆) to t₁₃, while thread t₁ moves to t₇ and thread t₂ moves to t₁₁. At time 4, thread t₀ is now at t₁₄, thread t₁ is now at t₈, and thread t₂ has reached t₁₂. At time 5, thread t₀ moves to t₄ before the other threads and during the last stage, thread t₁ and t₂ take the newly created threads t₉ and t₁₀.

For devices that store information, thread scheduling is used to outline a pattern of garbage collection.
This diagram displays a pattern of deleting information. The garbage heap is partitioned into clusters of equal size that fill in parallel sequence. If after a garbage collection, too little cluster space remains or the cluster space is too fragmented to satisfy the next garbage sweep request, a new cluster is allocated.

Students learn to relate components of a process and possible points of convergence or change to graphing terms such as vertex, segment and vector.

Locating moments or places of sensitivity, possible transfer or rerouting is a very flexible tool—patterns of transport and interchange of goods or pathways can be illustrated with technology specifically designed for students of marketing, commerce and industry. This analysis could also be used by music students, to design the location of a bridge or a modulation into a different key.

Social networking models show relationships and interaction flowing within an organization.

This network maps the airline hijackers who attacked the World Trade Center in the United States in 2003. Each member is color coded according to the flight they were assigned, and gray nodes show others reported to have had interaction with the hijackers, offering information or cooperative action.

Connecting pairs of nodes reveals the network of the organization. Network metrics tell the centrality of the participants, possibly indicating the significance of each. The distance between vertices represents the closeness of the connection. Different individuals can be identified: the connectors, the leaders, bridges, isolates, members of clusters, and members of the core. Thicker lines can indicate repeated interaction or closer cooperation or more important function. Notice the lines around the pilots.

As students create and understand models, their analytic skills and problem-solving abilities increase, in any field of study. The course concludes with a final project. Students in partners investigate a national or international problem, research primary sources for data, and design a graphic representation of one aspect of the problem. The models are created not to solve the problem; but to explain, demonstrate, trace, clarify or analyze a contributing factor. Throughout the course students will be encouraged toward expecting and understanding that the structure of every argument includes rules of evidence, and factual conclusions. They may become less inclined to accept superficial or baseless comments or opinions, on any subject. They may develop the ability to ask questions that have direct focus and content. They may come to feel they more thoroughly own their own decisions and opinions.

1.5 VALUE OF MATHEMATIC INTUITION IN THE LIBERAL ARTS

Societies survive in their institutions, passing on their valued knowledge and beliefs.

But no institution granting PhD’s ever solved one major problem—not economic, social, financial, or ecological. Problems are solved, and societies grow, through the insight and creativity of individuals or very small groups.

The math component of a Liberal Arts education develops thinking strategies that transfer to all disciplines, encouraging students to think with a plan and a purpose, to construct meaning from information, and to solve problems of all kinds.

The goals of human society remain the same: to survive, to remain safe and healthy,

to procure for citizens as large and wondrous a life as possible, to explore into the unknown, to share what has been learned, and to search for the mystery of our existence.

Our Mathematic Intuition provides us with a view of our human history and the ability to write our significance and vitality. It will advance the capacity for humans to explore, to care for our planet, and perhaps, to save us from ourselves.


FIGURES AND TABLES
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637
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638
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