# Technical Mathematics:
# Mechanical and Manufacturing Technology[1]

## CRAFTY Curriculum Foundations Project
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## Summary

For three days in October 2000, a team of community college faculty from mathematics departments and technical specialties met with industry representatives to define the mathematics requirements for entry-level technicians in manufacturing and mechanical technology. We also discussed our vision for the mathematics classroom of the future, including issues of theory versus application, instructional interconnections, methodologies, and delivery mechanisms.

We identified 13 mathematical skills areas in which students need a basic understanding. We also ranked 37 specific topics as high, medium, or low importance to students in this field. We recognize that degrees of specialization and differences among technicians in a manufacturing environment affect the ranking and depth of the topics.

We focused heavily on what employers expect from new technicians entering the workplace. Soft skills are very important: the ability to work in multi-disciplined teams and to communicate with other workers, engineers, managers, and customers. A technician must take real world data and information and use critical thinking skills to analyze a problem logically and formulate a solution. Troubleshooting equipment and processes is especially important in a manufacturing environment. A technician is also expected to use computer-based software for technical analysis as well as for communication and presentations.

We determined that a ratio of approximately 30% theory and 70% computation and application is the right mix in the classroom. We also agreed that students should be exposed to mathematics software and simulation, which are used in design and process planning and in statistical process control applications in business. All technicians should be able to use standard business software and the Internet for communication and presentation.

Our technical community college faculty felt that there should be major changes in the way college mathematics is taught today. The curriculum should be presented in a modular, just-in time format to suit the specific technical content area being taught. Mathematics problems must be realistic and relevant to

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the technical field being studied. Team teaching, with mathematics faculty entering apprenticeships with technology faculty, would improve the teaching of mathematics concepts and applications required in the content area. Faculty should experiment with different classroom approaches to provide real world experiences for the students. For example, they might use the studio approach to integrate lecture and laboratory exploration and experimentation. In this environment they should provide for student team problem solving and for the development of leadership and communication skills. Both students and faculty should have the opportunity for internships and capstone projects with industry.

# Narrative

## Introduction and Background

**Future Working Environment.** In the coming decade, technicians in mechanical and manufacturing facilities will continue to perform a variety of jobs ranging from product and process design and planning through product manufacturing, testing, and delivery and field support. With increased globalization of markets and manufacturing processes, the focus will be on higher value-added tasks and on leadership in creating innovative products.

Laboratory technicians operate sophisticated measuring equipment for product development, testing and qualification, and for product conformity verification. In metal manufacturing facilities, NC (numerical control) machinists set up equipment, optimize process control feeds and speeds, perform statistical process control to maintain and ensure product quality, and perform preventative maintenance on their equipment. Other technicians perform sub-system and system level tests, verify that products meet all specifications, and provide trouble-shooting support for products in manufacturing as well as products already fielded with the customer.

Teamwork, communication and problem solving skills, within plants and work teams as well as across global networks of design and manufacturing facilities, will continue to be critical success factors for the individual technician and for US industry.

**Technology Environment.** The working environment for technicians in mechanical and manufacturing facilities in the next decade will call for increased computer skills, as both product and manufacturing processes incorporate more imbedded microprocessors for enhanced product functionality and real-time process control.

Technology should influence the teaching and learning of mathematics through the use of PC based modeling tools. Students should analyze real world environments with computer-based simulations and study multiple scenarios without having to perform tedious number crunching by hand.

## Understanding and Content

**Establishing a Baseline for Mathematical Content.**

1. Teach students to identify the elements needed to set up an equation to solve a problem.
2. Decide at what level the use of calculators should be taught.
3. Equalize the preparation of incoming high school students. In some states high school students take their required mathematics in freshman and sophomore years, and then have a two-year gap before they take college entry mathematics tests. These students get discouraged in remedial mathematics classes, and a refresher class might be more effective. What do your incoming students need?
4. Demonstrate to high schools and two-year college students the importance of mathematics in general occupations and business today.
5. Train students to internalize mathematics skills. Application of real world problems would help with this internalization.

6. Recognize that the training for academic degrees (BS, MS, PhD) is completely different from the training for two-year technicians.
7. Provide bridge courses for job-oriented students in two-year programs to help them make the jump to a baccalaureate program.
8. Help advisors understand students' short range and long range plans.

**What mathematical topics and content must students master during the first two years in order to complete their AAS program or to enter the job market?**

We divide these topics in two groups. The first lists thirteen areas in which students should have a basic understanding. The second lists 37 specific topics and rates their importance.

***Areas of Basic Understanding.*** All students at this level should have a basic understanding of:

1. Applied basic statistics for quality control and general business applications
2. Applied basic trigonometry
3. Applied solid geometry
4. Basic shop mathematics
5. Scientific and engineering notation
6. Conversions
7. Significant figures
8. Decimal to percentage conversion
9. Algebra: Quadratic equations, simultaneous equations
10. Theory behind setting up equations (modeling), problem definition
11. For technology students, mathematics, English, history, etc. should not be taught in isolation.
12. Construction and interpretation of basic graphs
13. Transference of data to information to analysis (critical thinking)

***Topics Rated for Importance.***
Topics are rated as low (L), medium (M), or high (H) importance to students in this field. (See the table on the next page.)

**What mathematical problem solving skills must students master in the first two years?**

Technicians need more training in critical thinking and analytical skills for problem solving. Application problems should therefore include critical thinking and analytical activities.

**What is the desired balance between theoretical understanding and computational skill? How is this balance achieved?**

The balance between mathematical theory (book learning) and computation or real world application should be 30% for theory and 70% for computation and application.

**What mathematical topics are needed to advance up the career ladder and continue education to the bachelor's degree? What priorities exist among these topics?**

1. Understanding of order of operations
2. Fundamental arithmetic
3. Converting fractions to decimals and decimals to fractions

| | | | | |
|---|---|---|---|---|
| 1. | Mathematical models: development from verbal descriptions. | | | H |
| 2. | Problem solving: application of multiple concepts. | | | H |
| 3. | Integers: application in industry (differing concepts of zero) | | | H |
| 4. | Decimal system | | | H |
| 5. | Metric onversions – English to metric and metric to English | | | H |
| 6. | Order of operations | | | H |
| 7. | Ratios and proportions | | | H |
| 8. | Percentages | | | H |
| 9. | Approximation | | | H |
| 10. | Linear measurement | | | H |
| 11. | Powers and roots | | M | |
| 12. | Exponents | | M | |
| 13. | Logarithms (as related to areas in electronics, friction, etc.) | | | H |
| 14. | Angles | | | H |
| 15. | Radians (as conversions) | | | H |
| 16. | Decimal conversion to degrees/minutes/seconds and back | **L** | | |
| 17. | Geometric relationships (not geometry proofs) | | | H |
| 18. | Bisection of a line | **L** | | |
| 19. | Determining the center of a circle | **L** | | |
| 20. | Inscribed and circumscribed circles | **L** | | |
| 21. | Triangles, both right and oblique | | | H |
| 22. | Pythagorean theorem | | | H |
| 23. | Basic trigonometric functions: sine, cosine, tangent | | | H |
| 24. | Variables | | | H |
| 25. | Solution techniques for linear equations | | | H |
| 26. | Simultaneous equations; application of multiple methods | | | H |
| 27. | 2 D or general graphing skills | | | H |
| 28. | Quadrants: I, II, III, IV | | M | |
| 29. | Polar coordinates: introduction | | | H |
| 30 | 3 dimensional coordinate systems: $x$, $y$, $z$ | | M | |
| 31. | 5 axes & 6 axes: $x$, $y$, $z$, $a$, $b$, $c$ | **L** | | |
| 32. | Rates of change, conceptually understood (not requiring calculus) | | | H |
| 33. | Vectors: components, addition, subtraction | | M | |
| 34. | Basic statistics as applied to industrial quality assurance: mean, median, mode, standard. deviation, X-Bar & R, Range, skewness, average, trends | | | H |
| 35. | Pareto plots, histogram, scatter plots | | | H |
| 36. | Detecting trends in data sets | | | H |
| 37. | Interpolation and extrapolation | | | H |

4. Basic algebraic equations
5. Application of skills—especially important
6. Approximation and estimation: having a feel for the right order of magnitude, the right units of measure, and the appropriate precision for an answer
7. Cartesian coordinates

## Technology

### How does technology affect what mathematics should be learned in the first two years?

After introducing a topic or concept (such as linear equations) move immediately to the technology to speed computation in practical problems. Use technology to overcome tedious number crunching and allow consideration of many problems, introducing students to the real world environment of solving multiple problems.

Use computer-based modeling or simulation software. In the not too distant future every student may have access to a laptop. Laptops could actually be integrated into the classroom, especially in technology courses.Link mathematics software to application software in order to reinforce mathematical concepts.

### What mathematical technology skills should students master in the first two years?

Students need to be computer and calculator literate. This means our students should have experience with graphing calculators, word processors, spreadsheets, data base management software, and computer presentation applications such as *PowerPoint*. They should also have experience with mathematical and statistical software such as *Maple, Mathematica, Mathcad,* or *Statistica*.

## Instructional Techniques

### What are the effects of different instructional methods in mathematics on students in your discipline?

The "studio approach," employed in some mathematics courses, may better integrate lecture, lab, exploration, experimentation, etc., for our students. Cross-departmental team teaching has the potential to present mathematics in an applied context that can be more effective with students in technical fields. The use of collaborative problem solving teams reinforces important workplace skills of cooperation and team work.

### What instructional methods best develop the mathematical comprehension needed for your discipline?

For our students the best instructional methods are those that use real life hands-on applications, repetition, case studies, and computer simulations. Avoid teaching mathematics to simply teach mathematics. Move heavily to the application of the concepts within the mathematics classroom. Students gain much when instruction is coupled with internships, cooperative work assignments, or work shadowing arrangements.

## Instructional Interconnections

### What changes are needed in the mathematics curriculum in order to satisfy the needs of AAS students and technicians?

The traditional mathematics curriculum includes College Algebra, College Trigonometry, and Intermediate Algebra, all of which are set up to support the mathematical needs of the college as a whole. Technical mathematics courses are tailored to be program specific, and there are significant variations in such courses among the community colleges that offer them.

Devise curricula that provide mathematics instruction in a just-in-time format. When topics are needed in technology, physics, or science, the mathematics topics would be coordinated for delivery. We understand that this will not be easy. Faculty members will need to be extremely cooperative with each other. Mathematics instructors may need to apprentice in technology areas to learn the applications and understand which mathematics topics are important and when these topics are needed.

**What instructional methods might mathematics instructors use to develop or reinforce non-mathematical skills or understandings in your discipline or company?**

1. Team teaching
2. Emphasizing critical thinking
3. Demonstrating a logical approach to solution of a problem
4. Requiring report writing and presentation (communication)
5. Just-in-time teaching: teaching each mathematics concept and application as it is required in the content areas
6. Working together with technology colleagues to identify expectations, trying different approaches, adjusting the delivery to focus on desired outcomes
7. Including problems with a range of answers instead of a single answer
8. Using student teams on problem solving applications. Use of team problem solving techniques should begin as early as possible, because the skill develops over time.
9. Having students present *how* they solved a problem.

**How can dialogue on educational issues between your discipline and mathematics best be maintained?**

1. Increase and improve communication between faculty members in mathematics and the technical fields.
2. Integrate the mathematics department into the content area programs.
3. Allow better assessment of the outcome of classes in mathematics, English, and government by technology faculty. These departments are really in a support role, as opposed to classical or traditional mathematics departments.
4. Make sure that mathematics and other support curricula are not delivered in a vacuum, divorced from the technical content areas.
5. Recognize that the mathematical support of technical areas should differ from the mathematical preparation of transfer (academic) students. Change can be incremental: find one sympathetic mathematics faculty member, then a second, then a third, etc.
6. Establish an ongoing dialogue with industry representatives. Encourage industry participation on advisory committees.
7. Initiate faculty shadowing in industry, coops, and similar programs. These activities should be ongoing, not just every 3, 5, or 10 years.
8. Invite mathematics and English faculty to serve on technology advisory committees as active participants.
9. If possible, solicit student evaluation of their educational experience after their entrance into the workplace. (Some students or companies may be reluctant to do this.)
10. Establish dialogue with the high schools.

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# APPENDIX A: Examples and Vignettes

1. Machine shops today are moving to multi-axis, NC programmable equipment and machining cells, including very accurate CMM (Coordinate Measurement Machines).

   The operator/technician is expected to be able to setup this equipment, optimize the routing feeds/speeds for different materials, perform total productive maintenance (TPM) on the equipment and participate in Total Quality Management (TQM) such as Six Sigma Quality Management Tools, practiced in most U.S. Manufacturing companies today.

   Skills for set-up, NC optimization:

   Geometry, trigonometric functions, solving equations, measurement and conversion skills.

   Skills for Total Quality Management

   Statistics: mean, standard deviation, UCL, LCL,

   Histograms, scatter diagrams, average, range, etc.

   Other Skills expected or required in a modern manufacturing company:

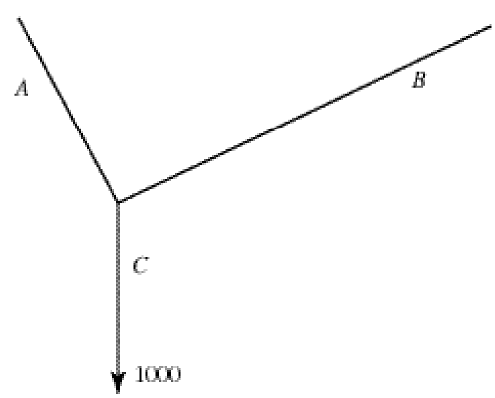
   Communication skills: written, oral, and computer (PowerPoint)

   Leadership skills

   Ability to work on teams, to be multi-disciplinary

   Ability to think logically, and to troubleshoot equipment and processes

2. Find the tension forces in cables *AC* & *BC* as shown in the following diagram:




   a. Draw the free body diagram.
   b. Place the vectors tip to tail to form a force triangle.
   c. Use the Law of Sines and Law of Cosines to find the force in the cables.
   d. Find the components of the unknown forces in Cables *AC* and *BC*.
   e. Using the components of the forces and the applied force, write the equations for

   $$FX = 0 \text{ and } FY = 0$$

   f. Solve the system of equations using a calculator and determine the force in each cable.

3. Teaching of Frequency Distribution: example with Alpha Bits. (Boxes made in different factories do have different frequency distributions. Marshmallow Alpha Bits have a different frequency distribution than "standard" Alpha Bits.)

a. Population: the contents of the box
b. Sample: 100 "letters" in the sample
c. Tally sheet: shows the frequency of each letter
d. Lot traceability: production lot on the box
e. Graph: the frequency distribution

4. 2D Graphing—using a formula to create an involute profile needed to produce a two-dimensional CAD drawing of spar gears.

5. Combination of strength of materials, manufacturing, and mathematics: design a container to hold and protect two eggs. The container should be able to protect the eggs when dropped off of a specified building. Build the container and drop it off the building: do the eggs survive? (No, you can't hard boil the eggs!) Other options and concepts can be added, such as:
   Assemble the container using at least two assembly methods.
   Assemble the container using at least two different materials.
   Use trigonometry to calculate the height of the "drop" building.
   Calculate the terminal velocity of the egg container.

6. Piping River Crossing. Schedule 80 pipe, 10 inches in diameter, is to be laid across this mile wide, fresh water river. The current is negligible and the river depth reaches 40 feet. The question: determine if the pipe will float when it is empty. Further questions:
   What is Schedule 80 pipe? (Internet research)
   Change to a salt-water river (sea water). The water density changes.

7. Building a fire sprinkler system: pipe pressures. How much pump pressure (head) PSI is required at ground level to operate fire sprinklers on the 8th floor of an office building? The following is the given information. Each story of the building is 12 feet high. Each sprinkler head is 9 feet above the floor, and the required pressure at the sprinkler head is 10 PSI. The length of the pipe is 300 feet and the friction loss in the pipe is 1.2 feet of head per 100 feet of pipe.

8. Swimming pool filling—volume, etc. Given the dimensions of a swimming pool, a hose delivering water at a specified rate (gallons per minute), and the cost of water per gallon, determine how long it will take to fill the pool and how much the water will cost. This will involve a conversion of cubic feet into gallons.

9. Ratios. Problems can involve 2-cycle engine oil ratios, cutting fluid ratios in machining situations, weed killer or yard fertilizer ratios. Problems centered on snow blowers and chain saws can also be devised. Or octane boosters for cars.

10. Automotive problems. Can involve miles per gallon, Kg/Gal, maintenance and operation costs.

11. Problems involving "grocery store mathematics" or "Home Depot mathematics" can be useful. These can involve converting fractions into decimals: "You and seven friends at the Brunswick Wild Oats Bakery have a $10 bill—how much can each of you spend?"

12. Proportions: using recipes such as in cooking or mixing cement.