Technical Mathematics:
Information Technology[1]

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Summary

Information Technology (IT) is a relatively young and rapidly evolving field. This ever-changing environment makes it difficult to identify the specific mathematical content in job skills for individual IT positions; in fact, many IT jobs require few particular mathematical skills. Significant developments in the IT realm, including web-based environments, suggest a focus on nonlinear thought processes, mathematical reasoning skills, and creative problem solving, rather than specific content. Therefore, academic mathematics preparation for students pursuing IT careers should not require advanced topics but should instead provide a solid foundation of elementary content, with a strong emphasis on the analytical ability needed to understand mathematical concepts.

These fundamental concepts and skills must prepare a student to enter the field initially, and must also provide a basis for lifelong learning, which may include seeking additional degrees. IT workers rarely need additional mathematical skills for professional development and career advancement, but do draw on the analytical skills acquired during their initial mathematics training.

Throughout this report, we emphasize that content and pedagogy should connect theory with applications. While few technicians use advanced mathematics on a daily basis, the ability to relate the correct mathematical concept to the problem at hand creates an IT technician with a future. The transfer of foundational knowledge to application skills early in the education of IT students will serve them well and will help them transfer these same concepts to new technologies in the course of their evolving careers. A technician educated in this manner is an asset to his or her organization and has the training needed to progress up the career ladder.

Many two-year schools must teach mathematical topics required by four-year colleges pursuant to transfer arrangements and articulation agreements. These agreements are often designed to enable students to continue to a baccalaureate degree, even though a high percentage of two-year students have no desire to follow that path. Although this mismatch was raised as a concern, it was deemed outside the scope of our discussion. For the purpose of this report, we focus on the mathematical skills students should master while completing the associate degree as an entry into the job market.

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Narrative

Introduction and Background

Technology changes very rapidly. "Timeless" skills that are relevant today and will remain relevant in the future are therefore very desirable. Technology demands problem-solving skills, a range of analysis tools from simple to sophisticated, the ability to identify and probe various approaches to a problem, and the ability to synthesize information to reach meaningful conclusions. These skills are useful in other disciplines as well as in the job environment. For example, students must be able to trouble-shoot (solve problems) in computer classes.

Students should be introduced to newer and more sophisticated technological tools used within their trade as they are developed. However, these tools should never replace abilities such as estimating, performing simple mental arithmetic with precision, or evaluating a tool's accuracy. Students should develop a comfort level with a variety of tools, an understanding of the associated applications, and a sound grasp of the mathematical concepts associated with the applications. They must understand the concepts in order to analyze a problem and select the most appropriate, efficient, and effective tool(s) to solve it.

Technology has eliminated the need for students to concentrate on the mechanics of mathematics, and attention has shifted to mastering tools. Tools as simple as spreadsheets and calculators are replacing the need for proficient computation. For example, statistical quantities are rarely computed today without such technological tools. To the extent that mathematics courses teach and reinforce the use of technological tools, IT students are well served.

Technology spans geographical and cultural differences today more than ever before. Students must learn to work effectively and efficiently no matter where their jobs take them. They must be comfortable working in various systems and moving between them in our global society. Currency conversion and fluency with the metric system of measurement are two simple examples of skills they will need in order to succeed. Furthermore, technology demands the ability to work in teams and to collaborate with others, and can thus influence the pedagogy of various disciplines.

Web-based environments and other IT settings suggest the need for nonlinear thought processes, and for one-to-many or many-to-many relationships, outside the traditional function model. Topics such as fractals, combinatorics and graph theory support this need, as do activities that require creative problem solving. For example, a computer security company may hire employees who are good hackers: people who are oriented towards nonlinear logic, people who find alternate paths. Analytical skills are still needed, but reliance on specific mathematical skills is diminishing.

Understanding and Content

We identify below the specific fundamental mathematical content appropriate for students pursuing IT technician careers through community college credentials. Although the particular mathematical concepts and skills needed may vary depending on individual IT career tracks, we believe all IT technicians would be well served by mastering this collection. It is also important to note that although not all of these concepts and skills are used on a day-to-day basis in targeted IT jobs, the mathematical environment supports the analytical mental training necessary for success and advancement in the IT field.

Foundation Content. Specific foundation content includes:

Basic arithmetic skills, including computational skills and use of calculators, decimal arithmetic, mental arithmetic, fractions, percentages, approximation, truncation and rounding, working with formulas and problems without "nice" answers.

Estimation skills and the ability to determine the reasonableness of an answer. (Examples of applications include estimating the volume of data in large databases, judging whether a report or calculation gives an answer of the correct magnitude, and determining whether a system is operating within expected ranges of performance.)

Conversions between different measurement systems, and knowledge of the metric system. (Accounting systems in the global market, which work with currency other than dollars, are an example of an application.)

Working with different bases (decimal, binary, octal, hexadecimal), numerical operations within the base, conversions between bases (including rounding errors, and divisibility issues). Applications include calculation of IP subnet masking required to support the number of subnets and hosts per subnet, and rounding or truncation errors caused by converting from the binary number system to base 10.

Basic geometry concepts, including perimeter, area, volume. (Design and deployment of a security camera system is an example of an application.)

Boolean algebra concepts, Boolean values and fundamental operations on Boolean values. (Expression of electrical networks in Boolean notation as an aid in the development of switching theory and in computer design is an example of an application.)

Fundamental concepts and skills of algebra, including variable manipulation and solving for a variable, linear systems of multiple variables, graphing in two dimensions, definition and basic properties of functions, basic properties of matrices, algorithms. (Spreadsheets and tables are applications of matrices.)

Fundamentals of statistics and probability, including data analysis and presentation, descriptive statistics, use of spreadsheets, and the use of probability and statistical models to draw inferences. (The collection, monitoring and interpretation of network/system performance measurements for network traffic control and load balancing are common job responsibilities for IT technicians. Other applications include large databases where reports are meaningful only when data are filtered through statistical terms, and the notion of "five 9s" of reliability, which refers to 99.999% uptime for systems such as telephones that must be dependable for 911 calls.)

Basic right triangle trigonometry, elementary trigonometric functions and their graphs. (Wavelength processing and interference issues in cabling systems are examples of applications.)

Accounting and related business mathematics concepts and terminology. (The wide range of IT applications dealing with financial systems provide examples. Although accountants may direct decisions, a basic understanding of terminology and concepts is very valuable for technicians. Other applications include cost/benefit analysis, ROI (return on investment), and payback concepts for interpreting technology decision support packages.)

Fundamentals of logic, logical connectives, truth tables, deductive reasoning, digital logic, logic gates, flip-flops. (The logic within the if… then/and… or statements inherent in software applications is an application, as are the basic troubleshooting approach to a systems failure for a system with n components, and the design of a sample data set to test a newly developed software system.)

While an in-depth exposure to mathematical theory may not be necessary, we believe that a survey course of miscellaneous topics emphasizing a variety of mathematical models is valuable. Mathematical modeling, problem-solving techniques, and challenging activities would be beneficial and appropriate. Fairly traditional content might serve the purpose, but it should incorporate nontraditional topics such as fractals, combinatorics, and graph theory that support creative problem solving. Students would be well served by skills in algorithm development and pattern analysis, as well as exposure to relational algebra, queuing theory, and set theory. An emphasis on multiple representations of data and visualization is very important.

Content for Advancement. Students may need additional mathematics for advancement up the career ladder or continuation into a baccalaureate program. It may be necessary for students to complete a bridge course in order to enter a baccalaureate program; such a course would expand upon the discrete mathematics concepts listed above and provide additional depth in such topics as set theory, counting theory, proofs, sequences and series, analysis of functions, and algorithmic design and analysis. Although we have not identified calculus as necessary or appropriate for IT, many computing degree programs do require calculus. Therefore IT students may need to study calculus in order to pursue baccalaureate or advanced degrees.

Mathematical Problem Solving Skills. All IT students should become expert problem solvers. To achieve this goal they do not need an extensive knowledge of algebra, but they do need the logical problem solving process used in solving algebraic problems. Algebraic problem solving skills include writing an equation to represent a problem: the dreaded “word problem.” IT students must be able to analyze a situation and develop an equation before the ability to solve an equation of a particular type is of value.

The ability to transfer information from one setting to another is very important. For example, even though an individual may be able to solve an equation, he or she must be able to transfer that ability to solving real-world problems. Problems that require students to apply a skill or concept from one area to a wholly different area are very valuable learning experiences.

Students should use a variety of problem-solving strategies (such as divide and conquer) to solve IT-based problems. Integrating mathematical concepts with practical application skills taken from the IT industry provides students with a reference point for the mathematics being studied. Application-based problems help students learn to derive equations from data and then conduct the appropriate analysis. Students should define the problem, collect the relevant data, perform all analysis, and make final recommendations in a report format.

In the field of IT, memorization is less important than the ability to use reference materials and other resources effectively. Problem-solving and analytic skills are critically important because, in the information age and in the IT field, there is simply too much to know. We recommend moving away from computational activities to more abstract problem solving and brainteaser exercises. Instructional techniques should emphasize the growing importance of creative team problem solving.

The problem-solving skills discussed in this report provide the mental processes needed to solve problems within IT systems. It is not necessary that students fully understand the related concepts; they should know they exist, how they are used, and how to choose the appropriate tool for a problem.

Technology

New technologies provide a multitude of instructional techniques. This rich environment can include both synchronous and asynchronous activities, providing students with opportunities to learn without being bound to a particular location.

Multimedia delivery systems, coupled with asynchronous personal contact time between students and faculty, allow instructors to cover difficult and challenging topics in more targeted ways. The asynchronous component of a course using this format should provide students with deeper understanding of the difficult concepts. As these new technologies are deployed, efforts to address a variety of learning styles and to provide all students with environments that promote individualized learning should be emphasized.

As instructional methods emerge, are tested and evolve, identifying methods that deliver the most effective and efficient learning experiences should be a priority. This emphasis on both quality of instruction and quantity of time invested reflects a growing awareness of cost-benefit analysis for education and its subsequent application in the workplace.

Instructional Techniques

IT-based applications should drive the development of mathematical theory and its use. At present it appears that theory is taught first, followed by application skills. In many cases, a mathematics professor teaches the theory within a traditional mathematics course, and an IT professional teaches the application skills. Theory and applications should be interwoven and integrated. Or, at least, applications should be considered first, and then theory, to ensure that theory is related to real-world concepts.

Teaching mathematics as a laboratory course with applications relevant to IT would enhance comprehension for IT students. Such a laboratory course could be incorporated directly into the IT program if the mathematics material were presented in learning modules. These modules might provide "just-in-time" mathematics instruction, allowing students to discover mathematical concepts within their IT applications. By demonstrating the relationship between the concept and its use, just-in-time mathematics instruction would be very beneficial for IT students.

Bringing applications into the mathematics class is an alternative approach. Theory could be taught as a follow-up to solving practical problems, rather than using applications to supplement theoretical development. In such a setting, mathematics faculty and IT faculty should work together to select examples and case studies relevant to the mathematics. Mathematics and IT faculty could develop and team-teach courses for IT and its associated mathematics.

Each concept will need a different balance between theory and application to ensure understanding. However, we believe that for technicians this balance will usually be 40% theory and 60% application. This ratio is not a fixed standard but provides a guideline. The balance for a given topic will depend on several factors, including the IT career being served, the level of schooling, and the application being addressed. As a rule, instruction should be centered on technique and application but well grounded in theory.

Combining mathematical concepts with IT applications should create interest in the underlying mathematical theory. This interest will allow students to form conceptual relationships between theory and applications within their daily jobs, and they will be able to build upon their educational foundation to create life-long learning experiences.

The nature of IT involves the IT technician in a constant process of adding new information, techniques and abilities to his or her portfolio. The methods and schedule of course work delivered in the traditional model do not address this need. Modularized content with clear objectives and measurable outcomes and delivered in alternate formats is needed to address ongoing professional development for IT workers.

Instructional Interconnections

Participation in summer internships in industry is an excellent way for mathematics teachers to understand the practical aspects of mathematics in the IT field. Afterwards, teachers are better equipped to explain why specific skills are needed in specific jobs, and to connect mathematical concepts with IT applications.

Internships can be excellent experiences for both students and teachers, and are strongly recommended. Such experiences provide answers to (legitimate) student questions such as "When am I ever going to use this stuff?" An instructor's ability to seat skills in practical real-world settings is a great motivator for learning. The IT industry wants students to see specific examples of how topics in their mathematics classes will be used on the job.

Creating IT-based case studies and interdisciplinary scenarios in mathematics courses would ensure the integration of mathematical concepts and their application. These case studies and scenarios should include problem definition, data gathering, data analysis, and problem resolution. They will involve students in defining relevant mathematical concepts, identifying theories and tools needed to solve the problem, processing data, reporting results, and providing all relevant documentation. This program will also develop skills in the areas of teamwork, time management, organization, and interpersonal relationships.

To accomplish this interdisciplinary work, faculty from the IT department and the mathematics department must work as a team. The team should discover, discuss and implement the interweaving of course material. Administration, faculty, and the institution as a whole must be committed to this effort.

There is an emerging trend for students to enter the IT field directly out of high school with only industry certifications and no post-secondary education. In today's market, students see numerous job opportunities and sometimes view higher education as a time impediment to pursuing a career. That employers continue to seek candidates with certifications rather than degrees is of growing concern. We recommend that high school and college mathematics instructors work together to address the content recommendations of this report and to advise IT students that post-secondary coursework allows for the life-long learning necessary for long-term career advancement.

One might ask whether some mathematical reasoning skills could be obtained from other disciplines. For example, can the ability to quantify data, to graph and plot data, and to identify the significant numbers in that data be obtained from biology, chemistry and physics, or perhaps the social sciences? We believe that the answer can be yes. Therefore, we promote the notion of mathematics across the curriculum, so that mathematical applications and reasoning skills can be addressed and reinforced in a variety of settings.

Students also need a foundation in the historical development of computing, and this material is typically included in overview IT courses. However, treatment of the subject could be improved by a coordinated mathematics curriculum, and we recommend that institutions link mathematical content with topics being discussed simultaneously in IT courses. We regret that, in many settings, mathematics courses are intentionally viewed as filters for entry into IT curricula, and we strongly recommend a more collegial and collaborative approach to educating students.

REFERENCES

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APPENDIX A: Definitions

As we explore the mathematical skills needed by Information Technology technicians, some definitions and concepts must be provided. The following list creates the context for our report and should provide the reader with an understanding of our audience and the scope of our discussion.

Asynchronous methods: Non-simultaneous (and typically time-independent) activities.Examples include threaded discussion groups and bulletin boards, list-serves, archived video, and other anytime technologies.

Community College: The mission of the community college is to provide the necessary and appropriate combination of education (theory) and training (skills) to ensure that exiting students are prepared to be successful in the careers they are pursuing, or in the baccalaureate programs they are entering. This mission also applies to students currently employed in the field but engaged in professional growth and development and the pursuit of life-long learning.

Information Technology (IT): The field of IT is a large and ever-changing realm. Within this report we include the fields described in the ACM report *Guidelines For Associate-Degree Programs To Support Computing In A Networked Environment*. We also include the positions generally envisioned as "modifiers/extenders" (those who "modify or add on to an information technology artifact") and "supporters/tenders" (those who "deliver, install, operate, maintain, or repair an information technology artifact") as defined in the CRA report *The Supply of Information Technology Workers in the United States*. Excluded are the intended graduates of the Computer Science, Computer Engineering, and Software Engineering programs as defined in the ACM/IEEE Computing Curriculum 2001 draft report (http://www.cs.rit.edu/~spr/CLQABS/schneider.html).

Synchronous methods: Simultaneous (and typically scheduled) activities. Examples include chat rooms, videoconferencing, live video, and other real-time technologies.

Technician: A technician is someone who will enter the IT job market with either industry certification or a community college certificate, AAS, AS or AA degree. These technicians are qualified for a wide variety of jobs and each position may have a wide range of needed skills. We have attempted to define the base skills needed for these graduates, filling all of these positions.

APPENDIX B: Examples and Vignettes

Subnet Masking

Subnet masking enables the TCP/IP protocol stack to determine where to send packets of data. It is a method used to segment a network and give each segment a network ID, so that other networks can still communicate with it.

Segmenting the network greatly reduces traffic, because not all computers are trying to use the same bandwidth. However, it is sometimes necessary to send packets of information from one network segment to another, and in such a case a bridge or router must be used to combine the networks.

A router is a device that can distinguish the destination network ID of a packet sent on the network by using the destination IP address and subnet mask. It can then route that packet accordingly, without having to send it to all the other network segments. If a packet is not intended for a computer on a specific segment, the router will filter out that packet to reduce traffic on the network, and send it only to the segment that contains the destination computer's IP address.

IP Addressing

An IP Address is a binary address consisting of four eight bit numbers, or octets. These octets can be converted back and forth between decimal and binary notation.

You may be accustomed to an IP address such as 192.168.1.1, but the computer sees this address as 11000000.10101000.00000001.00000001. All IP addresses have a total of 32 bits, or digits that can assume either a 1 or 0 value. Even if all eight bits were ones, an octet can only add up to 255. This is why the octets in IP addresses never go above 255; 11111111 = 255 .

Each IP address has an affiliated subnet mask. All IP addresses on one network segment should have the same subnet mask. The subnet mask tells the computers and routers how many of the 32 bits describe the network identifier, and how many are left over to describe the individual computer (or host). Once the network identifier has been resolved, routers know to what network to send the packet.

A subnet mask basically "masks" the corresponding bits in a binary number. For example, a subnet mask of 255.255.240.0 in binary is

11111111.11111111.11110000.00000000

The masked bits will determine what subnet an IP address belongs to. The unmasked bits, or zeroes, are the unique address of the computer within that subnet. There are 20 masked bits in the number above. That means that for two IP addresses to be on the same subnet with a mask of 255.255.240.0, their first 20 bits must be the same.

If the subnet mask were the same as above, 255.255.240.0, then

11110110.10001001.10100111.10100110 (246.137.167.166) and
11110110.10001001.10101110.00010011 (246.137.174.19)

would be in the same subnet because the first 20 bits are the same.

Similarly, the numbers

00101001.11101111.00011111.10101010 (41.239.31.170) and
00101001.11101111.00010101.11111111 (41.239.21.255)

are in the same subnet for the same reason. However, they are in a different subnet than the previous two numbers.

To discover the Network ID, or the number that starts that particular subnet, set everything else to zeros. The Network ID cannot be used as an IP address, because it is all zeros.

11110110.10001001.10100000.00000000

Converting back to decimal, this becomes 246.137.160.0

The Boolean "AND" function can easily determine Network ID's. Simply take the subnet mask and "AND" it with the IP address, also known as the Host ID. For example, if the subnet mask is 255.255.248.0 and the Host ID is 199.199.69.2, then we have

11111111.11111111.11111000.00000000 (subnet mask)

AND

11000111.11000111.01000101.00000010 (Host ID)

which give

11000111.11000111.01000000.00000000 = 199.199.64.0, the Network ID.

Determining Number of Hosts and Subnets

Determining the number of subnets and the number of available host IDs per subnet is another computation that utilizes IP addressing and subnet masks and is routinely performed by IT technicians.

The number of subnets is determined by the formula $2^n - 2$, where n is the number of masked bits, excluding those already predefined by the class type. For example, in the network ID of 192.168.1.0, with a subnet mask of 255.255.255.224, there are three masked bits counting from the Class C.

Provided Subnets = 2^3 – 2 = 6 subnets

The number of hosts/subnet is also defined by $2^n - 2$, where n is the number of unmasked bits. In the preceding example, there are five unmasked bits.

Hosts/Subnet = 2^5 – 2 = 30 hosts/subnet

The total number of hosts = hosts/subnet * subnets. In this case, it is 30*6, or 180 total hosts.

Here is a typical problem an IT technician might face in this area. You need to divide a Class C network into 12 subnets. How many bits should you mask, and what will be the subnet mask?

Solution: Use the formula $2^n - 2$. If $n = 3$, it provides for 6 subnets, which is not enough. However, if $n = 4$, it provides for 14 subnets, which is enough since not all subnets must be used. Because there are 4 masked bits, the subnet mask will be 11110000, or 255.255.255.240.

Trigonometry and Geometry

Provide the physical layout of an office, company, or building LAN, and determine the locations of network drops and cable lengths. Make efficient use of the cable to reduce costs (presuming approximately $1 per foot for cable). Avoid doors, lighting (RF interference), HVAC, etc.

This problem requires a student to explore the linear geometry of the space and to determine optimum (low use) cable lengths. Trigonometry can also be used to calculate such things as stresses on cable and cable runs when they are not properly supported. That is, to explore the vector analyses which can increase the load on a support member when weights are placed off center.

Geometry can be used to determine volume of network enclosures and cooling supply systems and to examine concepts of CFM, etc.

Relational Algebra

Within a table you need to query for results. These queries will need to create a relation between the entries in each table and create a cross product. The student should understand how to create the cross product and all potential errors that are possible.

Queuing Theory

Computer 1 (PC-1, with its own queue, Q-1), Computer 2 (PC-2, with its own queue, Q-2) and Computer 3 (PC-3, with its own queue, Q-3) are all requesting data from the Internet (sending data packets). These data packets are processed by a device called a router which has specialized software to deliver the data packets to the correct location. The router uses a queuing algorithm to process each of these packets, having its own queue to store all requests (Q-4). The problem occurs when PC-1, PC-2 and PC-3 create enough requests to fill both their own queues and the router's queue. The protocols and software on the router will halt all traffic from these queues until its own queue is stabilized.

Show the student how queues function and how the system will allocate resources to each of these systems and therefore cause the user to experience a slower response time.