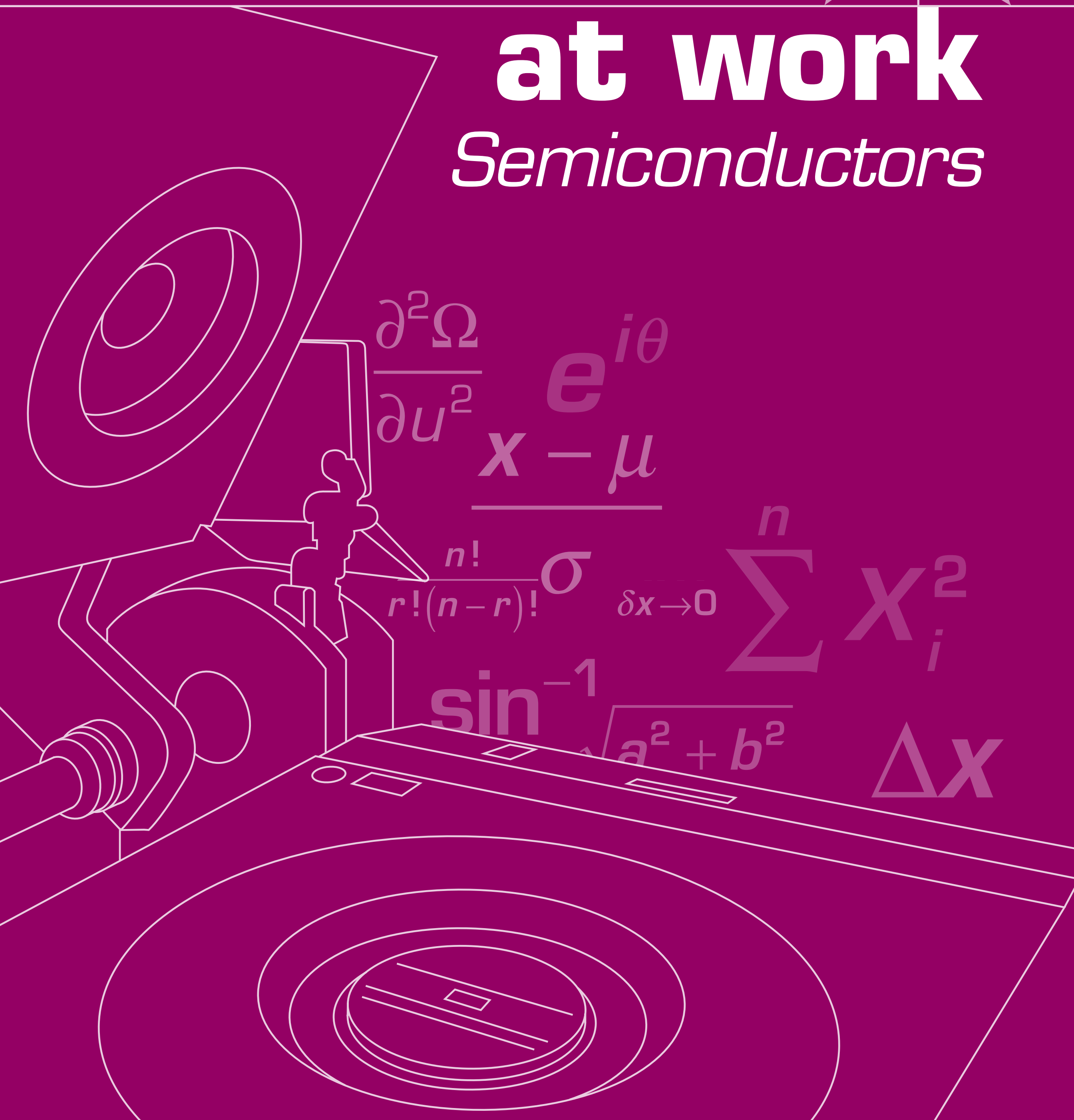
Achieve, Inc.

mathematics at work

Semiconductors



Mathematics in Semiconductor Manufacturing

The manufacturing industry has changed dramatically over the last decade. Nothing demonstrates this more than the growth in the semiconductor industry, which has made computers and cell phones possible and accessible on a large scale. Given the sophisticated skills needed for success in the high-tech workplace today, employers place a premium on an employee's ability to apply mathematical knowledge to solve problems. An education system that provides students with the quantitative thinking skills and knowledge necessary to translate information represented in different formats — coupled with the ability to engage in critical inquiry and problem solving — will be what keeps the skilled manufacturing industry in the United States on the cutting edge.

Available Manufacturing Jobs

Within the semiconductor manufacturing industry, there are a variety of entry-level jobs that pay well and provide opportunities for advancement. Individuals who participate in some form of postsecondary training — whether it is on the job, in a training center or at a community college — are often even better positioned to succeed in the manufacturing sector. An increasing number of employers and industries are requiring specialized training or education beyond a high school diploma. In addition to the semiconductor industry, other leading manufacturing sectors with good job opportunities include aerospace products and parts and electronic components.

Core Mathematics Knowledge in Today's Semiconductor Manufacturing Jobs

Developed by secondary, postsecondary, business, industry and government leaders, the national Career Cluster Pathway Plans of Study for *Production* and *Manufacturing Production Process Development* recommend a set of rigorous mathematics courses for students to take at both the secondary and postsecondary levels in traditional or vocational settings to pursue a career track in manufacturing. These Plans of Study show in detail how the foundation provided by courses such as Algebra I, Geometry, Algebra II, Trigonometry or Statistics, Computer Applications, and Applied Manufacturing Technology equips high school graduates with the mathematical knowledge and skills needed for success on the job. For more information on the Career Clusters Initiative, see www.careerclusters.org/resources/web/pos.cfm.

Jobs	Median yearly salary	Percentage of total jobs by education/training (ages 25–44)*		Number of total jobs		
		High school	Some college	2006	2016	% change
Electrical and electronic engineering technicians	$50,600	27%	54%	170,400	176,500	4%
Industrial engineering technicians	$46,800	27%	54%	74,900	82,400	10%
Team assemblers	$24,600	71%	25%	1,274,300	1,275,100	0%

*Remaining percentage of workers in occupation have a bachelor's degree or higher

Source: Bureau of Labor Statistics, U.S. Department of Labor, *Occupational Outlook Handbook, 2008–09 Edition.*

Ensuring College and Career Readiness: The American Diploma Project

In 2001, Achieve and several partner organizations launched the American Diploma Project (ADP) to identify a common core of English and mathematics academic knowledge and skills, sometimes referred to as "benchmarks," that American high school graduates need for success in college and the workforce. These ADP benchmarks, released in the 2004 report *Ready or Not? Creating a High School Diploma That Counts,* are the result of two years of intensive research conducted in colleges and universities as well as workplaces across the country.

The real-world expectations identified by ADP are significantly more rigorous than many current high school graduation standards — which helps explain why many high school graduates arrive at college or the workplace with major gaps in their English or mathematics preparation.

To help pinpoint the academic knowledge and skills required for future employment, ADP commissioned leading economists to examine labor market projections for the most promising occupations — those that pay enough to support a family and provide real potential for career advancement. ADP then surveyed officials from 22 industries, ranging from manufacturing to financial services, about the most useful skills for their employees to bring to the job.

ADP also worked closely with two- and four-year postsecondary faculty from five partner states to determine the prerequisite English and mathematics knowledge and skills required to succeed in entry-level, credit-bearing higher education courses. These conversations revealed an unprecedented convergence of the knowledge and skills employers and postsecondary faculty say are needed for new employees and freshmen beginning credit-bearing coursework to be successful.

"Mathematics at Work" Series

Following up on the work of ADP, Achieve has produced a series of "Mathematics at Work" brochures to examine how higher-level mathematics is used in today's workplaces. The brochures present case studies drawn from leading industries nationwide to illustrate the advanced mathematics knowledge and skills embedded in jobs that offer opportunities for advancement and are accessible to high school graduates.

The series underscores the value of a rigorous high school curriculum in mathematics. All high school graduates — regardless of whether they enroll in college, join the workforce or enter the military — benefit from acquiring a comprehensive knowledge base and skill set in mathematics.

To view or download the ADP benchmarks, go to www.achieve.org/ADPbenchmarks. To view or download a PDF of additional "Mathematics at Work" brochures, go to www.achieve.org/mathatwork.

$\sin^{-1}\theta$

$$\frac{x-\mu}{\sigma} \qquad \sum_{i=1}^{n}(x_i-\bar{x})^2$$

Career Preparation for Texas Instruments Manufacturing Specialists and Technicians

Experience has shown manufacturing companies such as Texas Instruments (TI) that the most effective manufacturing specialists and technicians have the ability to multitask; work effectively as members of a team; and possess a firm understanding of basic physics, chemistry and materials science. Even more fundamentally, TI believes that the foundation for the company's success is hiring employees who understand how to apply mathematical concepts across all manufacturing processes. Obtaining the math and science knowledge offered in high school enables many to begin their careers as entry-level manufacturing specialists and to pursue degrees following high school, which gives them the edge to truly excel.

> *"As manufacturing specialists, we had to understand key math concepts and sometimes even had to use pen and paper to verify we had the right answer to ensure quality."*
>
> Beth Kendrick
> Training Specialist
> Former Manufacturing Specialist
> *Texas Instruments*

Because of their strong foundation in mathematics, the most talented employees at TI can move from process to process as well as communicate across the organization about any particular task at hand. Understanding the language of mathematics allows manufacturing specialists and technicians to interact seamlessly on the production floor and ensures TI produces only the highest-quality electronic devices.

TI recognizes the need for its employees to arrive with core mathematical knowledge but also provides training to support continuous improvement. Although many hires arrive at TI with knowledge and skills they learned on the job, in high school or in a specialty occupation in the military, TI ensures that its new employees receive a thorough orientation to the applied mathematics behind the manufacturing process. The entry-level mathematics qualifying exam and subsequent training for manufacturing specialists cover many of the core concepts found in the ADP mathematics benchmarks. Key concepts include:

- Measurement systems (e.g., metric and non-metric, calibration studies)
- Statistical analysis (e.g., calculating mean, median, statistical distribution and deviation)
- Probability (e.g., percentages, outcomes)
- Interpreting charts and data (e.g., inputting and reading plotted arrays, interpreting spec and control lines)
- Basic algebra (e.g., one or more variables, multiple calculations)

Employees hired as manufacturing technicians at TI must possess a two-year degree and have additional advanced mathematical training in the areas of:

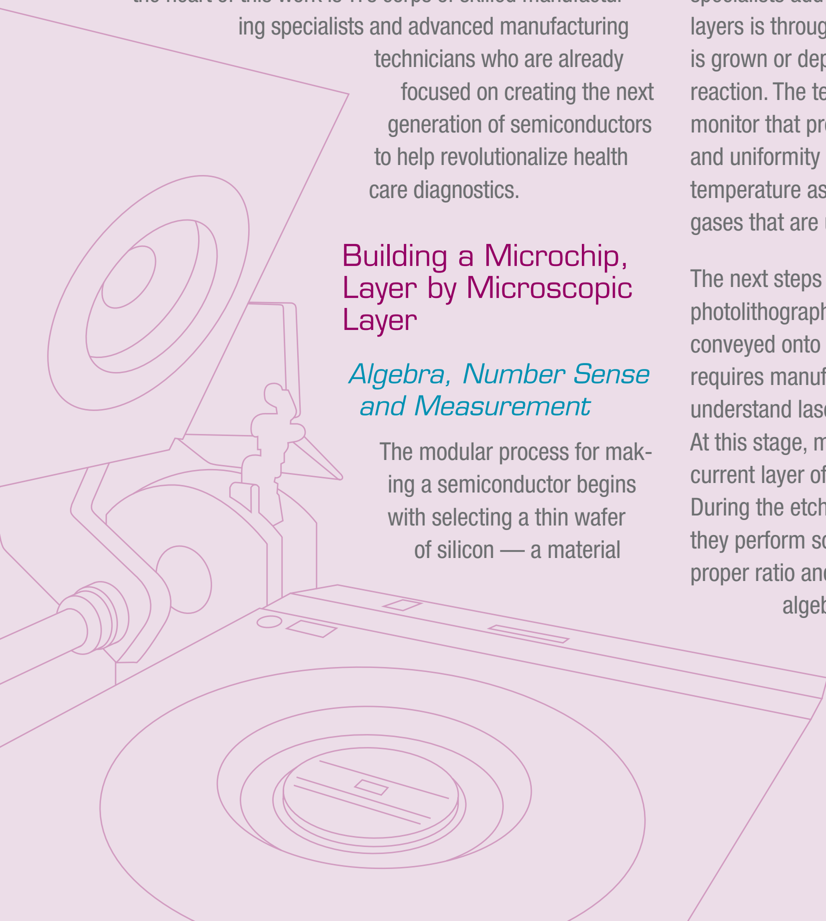
- Advanced algebra (e.g., power equations)
- Physics (e.g., gases and fluids, basic thermodynamics)
- Geometry (e.g., ergonomic analysis)

The intricacies of building semiconductors require an unprecedented level of mathematical precision and demand that co-workers can communicate flawlessly in the language of mathematics. Semiconductor manufacturing is made possible by workers who have a sophisticated understanding of how math is infused into each and every semiconductor TI produces.

Silicon Solutions: Mathematics and the Manufacture of Semiconductors

The world we live in today would not be possible without semiconductors. From the computer revolution of the 1980s to the communication revolution of today, semiconductors have played a crucial role in making computers and cell phones both portable and affordable to the public at large. But TI recognizes that this is only the beginning of the semiconductor revolution.

As the field of health care is poised for its own revolution, TI is at the leading edge in developing the microprocessors that power portable, accessible ultrasound and medical imaging technology that delivers life-saving electronics. At the heart of this work is TI's corps of skilled manufacturing specialists and advanced manufacturing technicians who are already focused on creating the next generation of semiconductors to help revolutionalize health care diagnostics.



Building a Microchip, Layer by Microscopic Layer

Algebra, Number Sense and Measurement

The modular process for making a semiconductor begins with selecting a thin wafer of silicon — a material that literally is a partial conductor, or "semiconductor," of electricity. Semiconductors are built by applying various layers on the silicon wafer. Each layer has a different purpose, such as making parts of the wafer more conductive, providing insulation between layers and electrical components, and connecting transistors. Materials specialists must closely monitor the semiconductor manufacturing process, including the dilution and concentration levels of chemicals, to create exactly the right environment for the chip.

A cleaned wafer is the initial foundation upon which specialists add layers of material. One method of adding layers is through a diffusion process in which material is grown or deposited on the wafer through a chemical reaction. The technicians and specialists measure and monitor that process to ensure that the precise thickness and uniformity are maintained. Keeping track of the temperature as well as understanding the physics of gases that are used are key elements at this stage.

The next steps are photolithography and etching. In photolithography, an image of the circuit being built is conveyed onto the surface of the added material, which requires manufacturing technicians to operate and understand lasers and other ultraviolet light sources. At this stage, manufacturing technicians must align the current layer of the chip to previous layers precisely. During the etching process to remove unwanted material, they perform sophisticated rate calculations to find the proper ratio and duration of chemicals to apply, requiring algebraic equations to determine how much and how long the surface of the chip should be exposed to the etching compounds. These steps require specialists and technicians to be proficient at converting angstroms, microns and nanoseconds into other measurement units to calculate rates.

The process of adding additional material and then imprinting and etching the circuit at successive layers — as well as creating conduits among layers so that different parts of the chip can connect to one another — requires 50 or more repetitive steps of adding, imprinting and subtracting material to create a semiconductor. Ensuring that the chip is oriented geometrically in exactly the same direction at every step of the process is crucial for building functional chips because the design is literally microscopic in detail and precision.

Technicians also may add layers of insulation, transistors or a final coating to protect the fragile chip architecture. The implant module, for instance, uses a concentrated electronic beam of ions to target particular sectors within a chip layer to make them more conductive. Materials specialists must understand how ions will interact with the chip architecture to measure and confirm the desired result. Maintaining careful records and plotting and interpreting results to check that they fall within manufacturing specifications and meet the desired outcomes of the chip designers and engineers require careful attention to detail.

Ensuring Quality Control

Data Analysis and Problem Solving

Statistical Process Control (SPC) is TI's quality control procedure that underlies all steps in the manufacture of semiconductors. For each process, engineers identify measurable process parameters. Manufacturing specialists use control charts to determine whether test results at any stage of production are outside of these control limits — a signal that the process needs to be adjusted. They are responsible for plotting and interpreting the data on these charts and taking the measurements that form the basis of the data sets used.

Maintaining a super-clean environment also is crucial for quality control. Manufacturing technicians constantly monitor the equipment for possible contaminants and have to mathematically determine precise ranges for temperature, air pressure and flow, light, and humidity. They also are in charge of testing and maintaining the machines involved in the manufacture of the chips — requiring a sophisticated understanding of mechanics and the mathematical processes underlying the equipment. By using the rules of probability and statistics to identify potential problems before they occur, technicians are often able to adjust the manufacturing process and equipment to prevent costly breakdowns.

Improved Productivity for Improved Health Care

By accurately performing their job responsibilities, manufacturing specialists and technicians help ensure maximum use of manufacturing equipment valued at hundreds of millions of dollars. They help minimize the number of unusable or "scrap" semiconductors while maximizing the reliability of those that pass their rigorous quality controls, and they offer valuable feedback to the team about ways to improve the manufacturing process via continuous data interpretation. Underpinning all of this is an advanced understanding of the role of mathematics, which ultimately leads to safe, affordable and accessible medical equipment — like the next generation of ultrasound machines — for everyone.

Mathematics + Teamwork = Success

TI understands that to stay at the forefront of the semiconductor manufacturing sector, it must hire employees who possess a strong foundation in mathematics. The processes and procedures in chip production are sophisticated and demand high levels of precision.

A closer look at the manufacturing process reveals that math plays a critical role at every stage. Cleaning the silicon foundation with a precise ratio of acids requires an understanding of the mathematical basis for the chemical reactions as well as the ability to read statistical data. The amount of additional material added at each step must be measured precisely for uniformity and thickness, which involves moving between metric and non-metric systems. When imprinting the circuit imagery that later is etched onto subsequent layers of the chip, manufacturing specialists must be aware of geometrical alignment and perform rate calculations to determine the correct ratio and duration of chemicals to apply during the etching process. Statistical analysis of data during the SPC reveals problems before they actually occur, keeping the manufacturing process running day and night to meet the ever-increasing need for semiconductors.

> *"Math is particularly important in this industry because of the critical processes required to build such technologically advanced devices. TI relies heavily on its employees to work together and build quality products using mathematical applications to monitor performance and overall quality."*
>
> Colette M. Kelly
> Thin Film/Implant Superintendent
> *Texas Instruments*

Because manufacturing specialists and technicians can be assigned to any of the production steps or modules employed in the creation of a chip, they must possess excellent teamwork skills. ADP research demonstrates that employers and professors alike identify collaboration and communication skills as critical factors for success. TI understands that to stay on the cutting edge and produce life-saving devices, like next-generation ultrasound machines, requires employees whose communication skills are well honed. Teamwork skills are prized as well because the iterative process of building up the thin layers of a semiconductor involves multiple steps carried out sequentially by a number of manufacturing specialists and technicians.

Because manufacturing specialists and technicians are involved at every stage of production, TI expects them to be able to problem solve together and collaborate on solutions that affect the bottom line. The success of TI's manufacturing teams lies in their ability to multitask, work together cohesively and communicate via a shared appreciation for mathematics — all of which are among the knowledge and skills embedded in the ADP college- and career-ready benchmarks.

About Achieve

Achieve, Inc., created by the nation's governors and business leaders, is a bipartisan, non-profit organization that helps states raise academic standards, improve assessments and strengthen accountability to prepare all young people for postsecondary education, careers and citizenship.

About the American Diploma Project (ADP) Network

In 2005, Achieve launched the ADP Network — a collaboration of states working together to improve their academic standards and provide all students with a high school education that meets the needs of today's workplaces and universities. The ADP Network members — responsible for educating nearly 85 percent of all our nation's public high school students — are committed to taking four college and career readiness action steps:

1. Align high school standards with the demands of college and careers.
2. Require all students to complete a college- and career-ready curriculum to earn a high school diploma.
3. Build college- and career-ready measures into statewide high school assessment systems.
4. Hold high schools and postsecondary institutions accountable for student success.

The world has changed, and high schools must change with it. The ADP Network is leading the charge in ensuring that all high school students graduate with a degree that works.

Visit our Web site for more information about the ADP Network and the ADP benchmarks (www.achieve.org/ADPbenchmarks) and to view additional "Mathematics at Work" brochures (www.achieve.org/mathatwork).

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