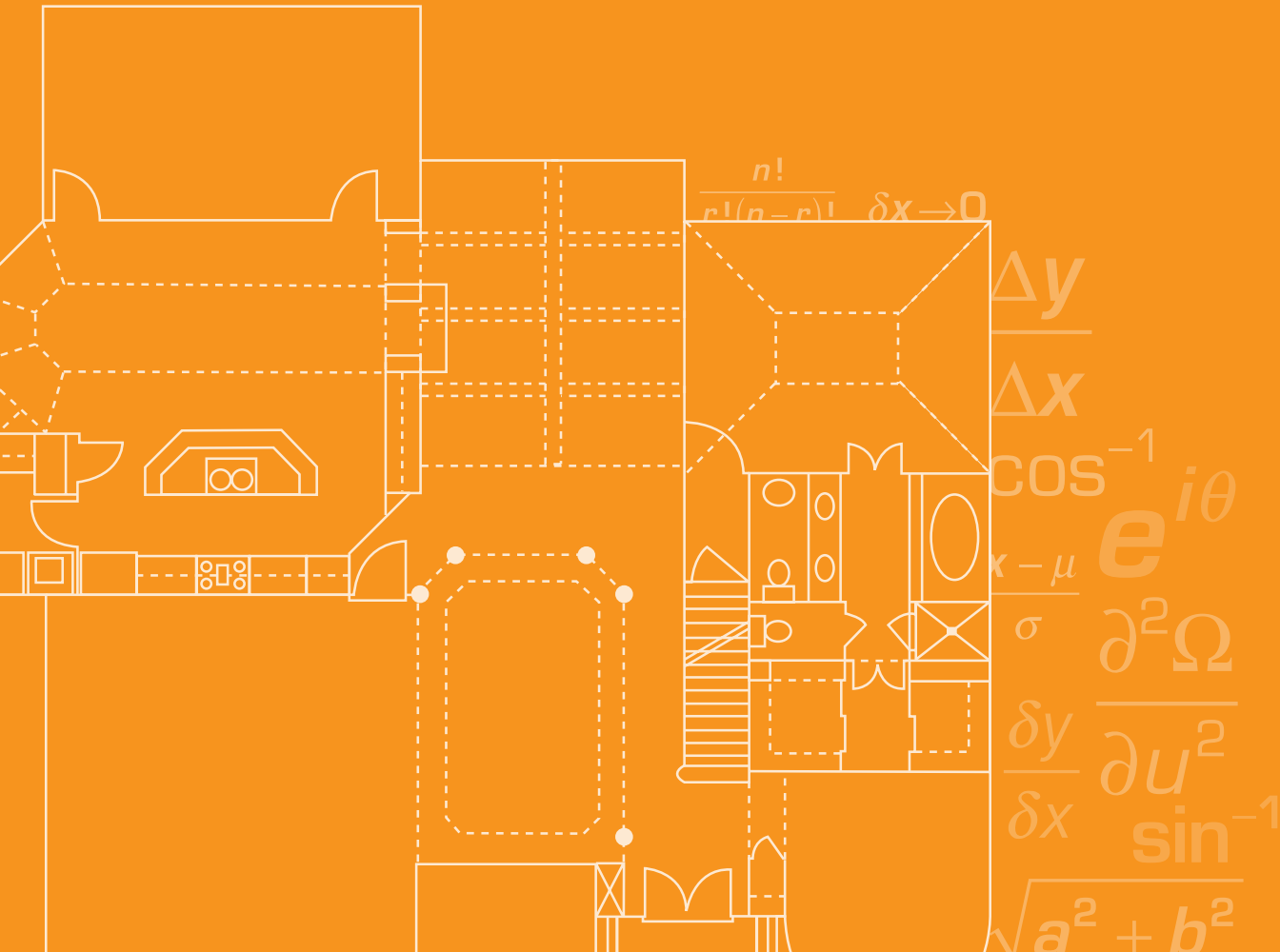


# mathematics

# at work

*Construction*



# Mathematics in the Construction Sector

The construction industry stands out as one of the largest industries in the country, employing more than 5 million individuals. Everyone working in the critical field of construction, regardless of their particular area of expertise or specialty, will use mathematics on the job each and every day. From the simplest measurements to the most complicated fittings, algebra, geometry and trigonometry are necessary for workers in this industry to do their jobs successfully.

## Available Construction Jobs

Within the construction industry, there are a variety of entry-level jobs that pay well and provide opportunities for advancement — jobs for high school graduates with postsecondary training or education but less than a four-year college degree. Construction is a field with true potential for upward mobility after sufficient on-the-job experience. With a significant proportion of self-employed — or family-employed — workers in construction, the construction industry offers many opportunities for workers to form their own firms and fulfill the American entrepreneurial dream.

## Core Mathematics Knowledge in Today's Construction Jobs

Developed by secondary, postsecondary, business, industry and government leaders, the national Career Cluster Pathway Plans of Study for *Construction* and *Construction Maintenance and Operations* 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 the construction sector. These Plans of Study show in detail how the foundation provided by courses such as Algebra I, Geometry, Algebra II, Trigonometry or Statistics, and Physics equips high school graduates with the mathematical knowledge and skills needed for success on the job. Until high school graduates understand the advanced mathematical skills used in the construction sector, they will remain unable to meet the demands of this high-growth industry. For more information on the Career Clusters Initiative, see [www.careerclusters.org/resources/web/pos.cfm](http://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/associate	2010	2020	% change
First-line supervisors/managers of construction trades and extraction workers	\$59,200	43%	32%	558,500	689,500	24%
Carpenters	\$40,000	43%	26%	1,001,700	1,197,600	20%
Construction and extraction workers	\$29,700	44%	23%	998,800	1,211,200	21%

Source: Bureau of Labor Statistics, U.S. Department of Labor, *Occupational Outlook Handbook, 2012–13 Edition*.

# The Common Core State Standards: Ensuring College and Career Readiness

The Common Core State Standards (CCSS) are K–12 mathematics and English language arts/literacy standards that identify the academic knowledge and skills all students need when they graduate high school to be ready for their next step, be it college, the workplace or the military. The CCSS were developed through a process managed by the National Governors Association and Council of Chief State School Officers and led by states. To date, more than 40 states have chosen to adopt and implement the CCSS.

In mathematics, the CCSS include focused content standards as well as Standards for Mathematical Practice, which articulate the ways students should apply mathematics both in school and on the job — to solve problems, reason abstractly and quantitatively, critique arguments, model, exercise precision, and look for

repeated reasoning. In English language arts/literacy, the CCSS include expectations for reading, writing, language, and speaking and listening, including students' ability to work in teams and communicate effectively in a range of settings.

The CCSS are anchored in college- and career-ready expectations, which start in grade 12 and are back mapped to the earliest grades. Students who graduate from high school having mastered the CCSS will be academically prepared for college-level courses and rigorous career training programs. Importantly, the CCSS represent the floor, not the ceiling, and students should engage in additional coursework and work-based experiences to help chart their career pathway.

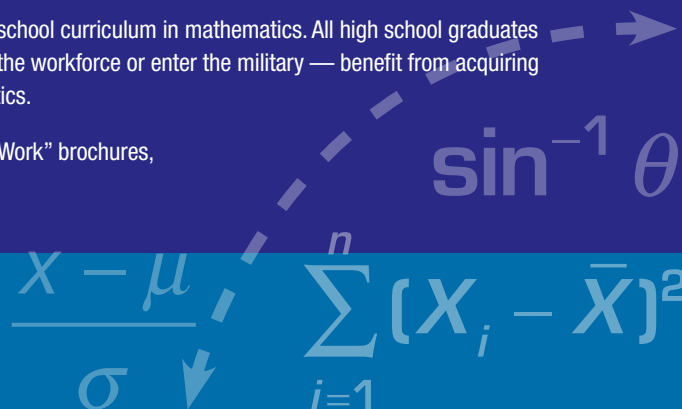
The CCSS can be found at [www.corestandards.org](http://www.corestandards.org).

## “Mathematics at Work” Series

First developed in 2008, using the American Diploma Project benchmarks as the foundation, Achieve produced a series of “Mathematics at Work” brochures to examine how higher-level mathematics is used in today's workplaces. Updated in 2013 to reflect the expectations set by the Common Core State Standards in mathematics, 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 graduates with some education and training beyond high school but less than a four-year degree.

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 college- and career-ready foundation in mathematics.

To view or download the full set of “Mathematics at Work” brochures, go to [www.achieve.org/math-works-brochures](http://www.achieve.org/math-works-brochures).



# Mathematics builds

## Career Preparation for the Construction Industry

The construction industry is filled with individuals with all sorts of backgrounds and training. The freedom of not being restricted by one specific degree or certification allows anybody with an interest in construction, an ability to work as part of a team and a keen understanding of mathematics to be successful in this field.

Many individuals learn the construction trade as part of a rigorous career and technical education (CTE) program starting in high school. In many communities, high schools and community colleges are joining together to develop integrated programs of study that allow students to master the classroom learning — in particular the advanced mathematics — critical to the construction industry while gaining hands-on experience through work-based learning. Students can earn a high school diploma while developing an understanding of the construction business from the inside. Some pathways include fully integrated courses that teach advanced mathematics content through construction projects such as building a house for Habitat for Humanity or remodeling a wing of a high school, as well as other rigorous academic and career-oriented courses.

Although there is no mandatory degree or certification that individuals need to enter the construction field, many employers place a premium on such distinctions. The National Center for Construction Education and Research (NCCER), an organization dedicated to addressing the industry shortage of contractors (persons who oversee all project aspects during the construction or development of a property), provides standardized construction and maintenance curricula to high schools, community colleges and individuals. NCCER offers a certification assessment and portable credentials that signal an individual's career readiness. Assessment results

are maintained in NCCER's National Registry, through which employers can find qualified employees.

NCCER's curricula run the full spectrum of building competencies, from carpentry and construction technology to other specializations including welding, site layout and even hydro-blasting. Present throughout the curricula's performance objectives are rigorous mathematical concepts and applications also found in the Common Core State Standards. For example:

- Carpentry (e.g., scale factor, isoclines/lines of constant elevation, angular measurement and conversions, calculations with decimals and fractions)
- Construction Technology (e.g., unit conversions, Pythagorean theorem, sampling methods, right-triangle trigonometry, volume of cylinders)
- Site Layout (e.g., angles and geometric figures; powers and square roots; unit conversions for lengths, areas and volumes; interpreting drawings; ratios and proportions)
- Project Supervision (e.g., bar graphs, network diagrams, rates of productivity)

More than 2,000 schools in the United States use NCCER's curricula, and about half of the states have built these curricula and assessments into their CTE construction pathways. Regardless of whether individuals receive credentials from NCCER, earn an associate degree in a relevant field or learn their trade on the job, they will need a solid foundation in mathematics to truly be prepared for a lifelong career in construction. For more information on NCCER, see [www.nccer.org](http://www.nccer.org).

# the foundation

## Construction Calculations: The Mathematics of Building Homes

Each month, almost a million permits are issued for the construction of new homes — and another 500,000-plus privately owned residential construction projects are completed. Construction is a critical industry in our economy, and mathematically adept workers in this industry remain in high demand. The popular notion of a carpenter with a tape measure is far from the truth of today's sophisticated approach toward construction, which involves much more than simple measurements. Also, with more than 1 million self-employed or small-business contractors in this industry, contractors need both steady hands in construction and steady heads for business. From pouring the foundation to managing costly projects in an ever-changing industry, the success of contractors as both builders and entrepreneurs is tied to their ability to apply advanced mathematics.

### Laying the Physical Foundation

#### *Number Sense, Geometry and Trigonometry*

In an ideal world, contractors would erect every home on level ground. As this is rarely the case, most home-building projects begin by reshaping the land. Calculating the slope of the ground starts a lengthy process of determining cut-and-fill areas so that the foundation rests on even ground. To minimize their costs, contractors and their teams need to site the foundation in ways that reduce the amount of material needed to create a level surface. Mathematically adept contractors and surveyors may even position a house precisely so that any removed soil can be “recycled” as fill elsewhere.

All experienced contractors know the importance of right angles and double-checking using the 3-4-5 rule. However, the fashionable curved walls and winding hallways of modern construction are built on customized, irregularly shaped foundation slabs that require builders

to be familiar with calculating lengths and areas using advanced mathematical skills that depart from the traditional tape measure approach.

“*Understanding mathematics is central to all aspects of running my business. I use mathematics every day on my work sites to make sure my houses are built strong and in my office so that my books are always balanced.*”

Keith Hayashi, Esq.  
*Herbert Chock & Associates, Inc.*  
*Construction/Engineering Consultants*

At this initial stage of home construction, contractors must work with structural engineers to determine the weight-bearing capacity of the foundation to prevent any structural hazards when the foundation later settles. It is critical while framing the foundation to determine the precise distribution and volume of concrete needed to ensure the building's structural integrity. Because reliable calculations at this stage of the process are essential for the foundation to be poured properly and the structure erected successfully, contractors must be able to both read sophisticated architectural plans coded in the language of mathematics and rely on their own construction teams' measurements (see box on next panel for an example).

Once the foundation has been laid, the work of a contractor has only just begun. Framing a house requires understanding every aspect of construction, and contractors must manage others and ensure that every calculation is exact. Installing a staircase requires calculating the rise and length of each stair with precision to ensure no missteps.

$$[X_i - \bar{X}]^2$$

$e^{i\theta}$

## Building from the Bottom Up

The area of the concrete floor needed in this house is the area of the orange rectangle *plus* the extra parts of the library, grand room, garage, laundry/morning room and foyer. The areas of various rooms outside the orange rectangle that must be calculated are:

$$\text{Library: } A_l = (13' 9'' - R)(11' 4'') + \pi R^2/2 - (l_3 - l_7 - 14')(11' 4'')$$

$$\text{Grand Room: } A_g = 15' l_5$$

$$\text{Garage: } A_c = (l - l_3)(21') + l_1 W_1$$

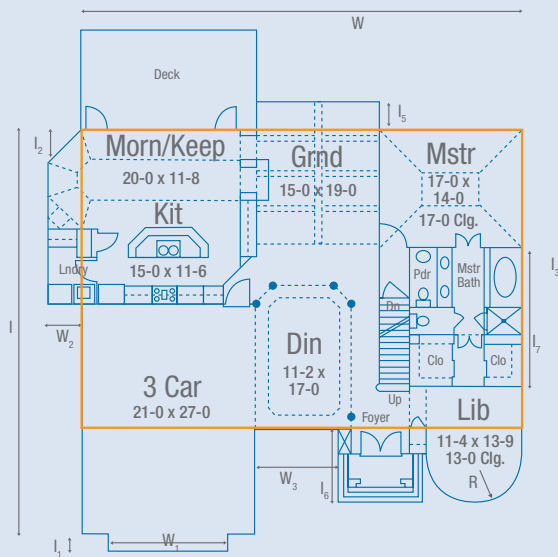
$$\text{Laundry/Morning Room: } A_m = (11' 6'' + 11' 8'') W_2 - l_2 W_2 / 2 = (23' 2'' - l_2/2) W_2$$

$$\text{Foyer: } A_f = l_6 (W - 21' - W_3 - 11' 4'')$$

Therefore, the *area* of the concrete floor is:

$$A = l_3 W + A_l + A_g + A_c + A_m + A_f$$

The *volume* of concrete that needs to be ordered, in cubic feet, is equal to  $V = A h$ , where  $h$  is the thickness of the concrete block in feet.



Doors and windows must be hung plumb, level and square, or they will not close properly. Installing the right volume of insulation between the studs and the ceiling so that plumbers and electricians can run the correct lengths of pipes and wiring safely behind the drywall requires a whole host of mathematical calculations from everyone involved in the construction project. Even the final steps of completing a house — laying down the tiles in the kitchen and the hardwood floor in the living room — are dependent on knowing how to calculate irregularly shaped areas to leave behind the least amount of scrap and save costs.

## Laying the Financial Foundation

### Number Sense, Algebra and Forecasting

The best contractors are those who rigorously plan before they build. Evaluating potential costs for their project estimates is crucial for the financial well-being

of their businesses. Contractors have to factor in the costs of labor, materials and equipment rentals to make hiring and purchasing decisions that maximize their return on time and energy. Contractors also must identify overhead costs (or additional indirect labor costs) and determine a gross margin percentage (or the “mark-up price”) to charge their clients enough to make a profit, which can be further complicated by fluctuations in the cost of labor and materials and rates of inflation. When first starting up, expanding their business or financing a project, contractors need to understand the dynamics of interest rates and compound interest to get the best rate possible to meet their business needs and pay off their loans in a timely fashion. Lastly, contractors need to understand prevailing conditions in the housing market to judge whether a project is likely to turn a profit and weigh those profits against potential risks.

$n!$

$(n - r)!$

$$\sum_{i=1}^n X_i^2$$

$u^2$

$\lim_{\delta x \rightarrow 0}$

$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

## Mathematics + Teamwork = Success

Although contractors rely on their knowledge of mathematics at every stage of the construction process, teamwork and communication skills play an equally important role in the success of construction projects of any size or type. From pouring the foundation to raising the roof, mathematics is integral to building a home or other property — and without the ability to communicate with and motivate a range of people, those calculations are not enough to convert blueprints into physical buildings. To be a successful small-business entrepreneur, today's contractor must be adept both at mathematics and team leadership.

The marriage of mathematics and teamwork is apparent throughout the construction process. Contractors have to work with equipment operators to clear and level the site, calculating precisely where to locate the structure and how much land to move. They need to read architectural plans coded in the language of mathematics and talk to structural engineers to ensure that the foundation is and will remain structurally sound. They must lead a construction crew in framing the house and ensure that every joint fits precisely and every door is hung level. They have to work with materials providers to purchase the right amount of shingles and bricks. They also need to be able to calculate true labor costs relative to the small-business loans needed to run their enterprise.

The fact that today's employers and employees need both mathematics and teamwork skills should not come as a surprise. Research shows that to be successful on a job site or in the college classroom, workers and students

alike must be able to communicate, collaborate and apply mathematics. The most successful contractors can talk the language of entrepreneurs with their bank, speak to fellow small-business owners to purchase goods and services, and communicate with their subcontractors and employees on the job. Without core teamwork skills and a strong understanding of mathematics, contractors will be unable to be competitive in the growing construction industry.

The contractors of tomorrow must graduate from high school with the mathematical knowledge and teamwork skills that will allow them to succeed in the industry and offer them the opportunity to start their own businesses someday. The college- and career-ready Common Core State Standards provide the surest measure for today's students to graduate high school with the academic skills needed to build homes and construction businesses for the next generation.

“Everyone on a highway construction crew needs good math skills to correctly calculate quantities, measurements, supply orders. ... Pretty much every aspect of construction involves some level of math skills.”

James Thomas, Safety Director  
Callanan Industries, Inc., Schenectady, New York

$\delta x$

$2 \sqrt{a^2 + b^2}$

$\cos^{-1} \theta$   
 $\sqrt{a^2 + b^2}$   
 $(X_i - \bar{X})^2 e^{i\theta}$

A decorative graphic at the top of the page features a dashed orange arc. Inside and around the arc are mathematical formulas in a light orange color:  $\cos^{-1} \theta$  at the top left,  $\sqrt{a^2 + b^2}$  in the middle left, and  $(X_i - \bar{X})^2 e^{i\theta}$  at the bottom left.

## About Achieve

Achieve, 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 academic content standards with the demands of college and careers;
2. Establish graduation requirements that require all students to complete a college- and career-ready curriculum;
3. Develop statewide high school assessment systems anchored to college- and career-ready expectations; and
4. Create comprehensive accountability and reporting systems that promote college and career readiness for all students.

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.

For more information about Achieve and the ADP Network, visit [www.achieve.org](http://www.achieve.org). To view additional "Mathematics at Work" brochures, visit [www.achieve.org/math-works-brochures](http://www.achieve.org/math-works-brochures).

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