Comprehensive LaTeX Template for Undergraduate Mathematics

For Social Science Graduate Programs and Data Science Careers

SPEC
SECURITY AND POLITICAL ECONOMY LAB

A Resource Guide for Undergraduate Students and Research Assistants

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Introduction to This Template

This document serves as both a template and a guide for typesetting mathematical documents using LaTeX. It covers basic structures, mathematical notation, theorems, proofs, and other elements commonly used in undergraduate mathematics.

Note

Throughout this template, you'll find explanatory notes like this one that provide additional context and tips for working with LaTeX.

Tip

Most LaTeX editors support auto-completion. Try typing a backslash (
) followed by the first few letters of a command to see available options.

Basic Mathematical Notation

This section demonstrates how to typeset common mathematical expressions.

Inline vs. Display Mathematics

Mathematics can be written inline within text using `$...$` or as displayed equations using `\[...\]` or the `equation` environment.

Inline math example: The quadratic formula $x = \frac{-b\pm\sqrt{b^2-4ac}}{2a}$ gives solutions to $ax^2+bx+c=0$.
Display math example:

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

Numbered equation:

$$E = mc^2 \tag{1}$$

Note

Use inline math for simple expressions that fit naturally within text. Use display math for complex expressions or those you want to emphasize.

Common Mathematical Symbols

1.2.1 Arithmetic Operations

$$a + b = \text{addition} \tag{2}$$
$$a - b = \text{subtraction} \tag{3}$$
$$a \times b \text{ or } a \cdot b = \text{multiplication} \tag{4}$$
$$a \div b \text{ or } \frac{a}{b} = \text{division} \tag{5}$$
$$a^b = \text{exponentiation} \tag{6}$$
$$\sqrt{a} = \text{square root} \tag{7}$$
$$\sqrt[n]{a} = \text{nth root} \tag{8}$$

1.2.2 Relations

$$a = b \quad \text{equality} \tag{9}$$
$$a \neq b \quad \text{inequality} \tag{10}$$
$$a < b \quad \text{less than} \tag{11}$$
$$a > b \quad \text{greater than} \tag{12}$$
$$a \leq b \quad \text{less than or equal to} \tag{13}$$
$$a \geq b \quad \text{greater than or equal to} \tag{14}$$
$$a \approx b \quad \text{approximately equal to} \tag{15}$$
$$a \sim b \quad \text{similar to} \tag{16}$$
$$a \propto b \quad \text{proportional to} \tag{17}$$

1.2.3 Set Notation

$$a \in A \quad \text{element of} \tag{18}$$
$$a \notin A \quad \text{not an element of} \tag{19}$$
$$A \subset B \quad \text{subset of} \tag{20}$$
$$A \subseteq B \quad \text{subset of or equal to} \tag{21}$$
$$A \cup B \quad \text{union} \tag{22}$$
$$A \cap B \quad \text{intersection} \tag{23}$$
$$A \setminus B \quad \text{set difference} \tag{24}$$
$$\emptyset \quad \text{empty set} \tag{25}$$
$$A \times B \quad \text{Cartesian product} \tag{26}$$

1.2.4 Number Sets

$$\mathbb{N} = \{1, 2, 3, \ldots\} \quad \text{natural numbers} \tag{27}$$
$$\mathbb{Z} = \{\ldots, -2, -1, 0, 1, 2, \ldots\} \quad \text{integers} \tag{28}$$
$$\mathbb{Q} = \{\frac{p}{q} : p, q \in \mathbb{Z}, q \neq 0\} \quad \text{rational numbers} \tag{29}$$
$$\mathbb{R} = \text{real numbers} \tag{30}$$
$$\mathbb{C} = \{a + bi : a, b \in \mathbb{R}, i^2 = -1\} \quad \text{complex numbers} \tag{31}$$

1.2.5 Logical Symbols

$$p \wedge q \quad \text{logical AND} \tag{32}$$
$$p \vee q \quad \text{logical OR} \tag{33}$$
$$\neg p \quad \text{logical NOT} \tag{34}$$
$$p \Rightarrow q \quad \text{implication (if } p \text{ then } q\text{)} \tag{35}$$
$$p \Leftrightarrow q \quad \text{equivalence (if and only if)} \tag{36}$$
$$\forall x \quad \text{for all } x \tag{37}$$
$$\exists x \quad \text{there exists } x \tag{38}$$
$$\nexists x \quad \text{there does not exist } x \tag{39}$$

Tip

Define your own commands for frequently used symbols to save time and ensure consistency. See the preamble of this template for examples.

Advanced Equation Formatting

Multi-line Equations

The `align` environment is useful for multi-line equations, especially when you want to align them at a specific point (typically equals signs):

$$\begin{aligned}
(a+b)^2 &= (a+b)(a+b) && (40)\\
&= a^2 + ab + ba + b^2 && (41)\\
&= a^2 + 2ab + b^2 && (42)
\end{aligned}$$

Note

Use the & symbol to specify alignment points in multi-line equations.

For equations without alignment points, use the `gather` environment:

$$f(x) = ax^2 + bx + c \tag{43}$$
$$g(x) = dx^3 + ex^2 + fx + g \tag{44}$$
$$h(x) = \sin(x) + \cos(x) \tag{45}$$

Cases

The `cases` environment is perfect for piecewise functions:

$$|x| = \begin{cases} x & \text{if } x \geq 0 \\ -x & \text{if } x < 0 \end{cases} \tag{46}$$

Matrices

LaTeX provides several environments for matrices:

2.3.1 Basic Matrix

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \tag{47}$$

2.3.2 Matrix with Square Brackets

$$B = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} \tag{48}$$

2.3.3 Matrix with Curly Braces

$$C = \begin{Bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{Bmatrix} \tag{49}$$

2.3.4 Matrix with Vertical Bars (Determinant)

$$|D| = \begin{vmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{vmatrix} = d_{11}d_{22} - d_{12}d_{21} \tag{50}$$

Warning

Be careful with large matrices! They can easily extend beyond page margins. Consider using smaller font sizes or breaking them into smaller components when necessary.

Limits, Sums, and Integrals

2.4.1 Limits

$$\lim_{x \to 0} \frac{\sin x}{x} = 1 \tag{51}$$

2.4.2 Sums

$$\sum_{i=1}^{n} i = \frac{n(n+1)}{2} \tag{52}$$

2.4.3 Products

$$\prod_{i=1}^{n} i = n! \tag{53}$$

2.4.4 Integrals

$$\int_a^b f(x)\,dx \tag{54}$$

$$\oint_C f(z)\,dz = 2\pi i \sum \operatorname{Res}(f, a_k) \tag{55}$$

$$\iint_D f(x,y)\,dx\,dy \tag{56}$$

$$\iiint_E f(x,y,z)\,dx\,dy\,dz \tag{57}$$

Tip

Notice the `\,` command before `dx` in integrals. This adds a small space that improves readability.

Theorems, Proofs, and Definitions

Mathematics papers and assignments often include theorems, lemmas, proofs, and definitions. LaTeX provides structured environments for these elements.

Theorem Example

Theorem 3.1 (Pythagorean Theorem)**.** *In a right triangle with sides a, b, and hypotenuse c, we have*

$$a^2 + b^2 = c^2 \tag{58}$$

Proof. Consider a right triangle with sides a, b, and hypotenuse c. We can place this triangle in a coordinate system such that one vertex is at the origin $(0,0)$, another at $(a,0)$, and the third at $(0,b)$.

The distance from $(0,0)$ to (a,b) is given by the distance formula:

$$c = \sqrt{(a-0)^2 + (b-0)^2} \tag{59}$$

$$c = \sqrt{a^2 + b^2} \tag{60}$$

Squaring both sides:

$$c^2 = a^2 + b^2 \tag{61}$$

■

Lemma 3.2. *Let a, b, and c be positive real numbers. If $a < b$ and $b < c$, then $a < c$.*

Proof. Since $a < b$, we have $b - a > 0$.

Since $b < c$, we have $c - b > 0$.

Adding these inequalities:

$$(b-a) + (c-b) > 0 \tag{62}$$

$$c - a > 0 \tag{63}$$

Therefore, $a < c$. ■

Definition Example

Definition 3.1 (Continuous Function)**.** *A function $f : X \to Y$ between topological spaces is continuous if for every open set $V \subset Y$, the preimage $f^{-1}(V) \subset X$ is open.*

Remark 3.1. *For functions $f : \mathbb{R} \to \mathbb{R}$, this is equivalent to the ε-δ definition: f is continuous at a if for every $\varepsilon > 0$, there exists a $\delta > 0$ such that for all x with $|x-a| < \delta$, we have $|f(x) - f(a)| < \varepsilon$.*

Example 3.1. *The function $f(x) = x^2$ is continuous on $\mathbb{R}$. To verify this using the ε-δ definition, let $\varepsilon > 0$ be given. We need to find $\delta > 0$ such that $|x^2 - a^2| < \varepsilon$ whenever $|x-a| < \delta$.*

Note that $|x^2 - a^2| = |x+a||x-a|$. If we restrict to $|x-a| < 1$, then $|x| < |a| + 1$, so $|x+a| < 2|a| + 1$. Thus, we can choose $\delta = \min\{1, \frac{\varepsilon}{2|a|+1}\}$.

Tip

The theorem environments are all numbered automatically. To reference them elsewhere in your document, add a label with `\label{name}` and then refer to it with `\ref{name}`.

Structuring Homework Assignments

For most undergraduate mathematics courses, homework assignments follow a simple structure with numbered problems and subproblems.

Basic Problem Structure

Problem 1

Prove that for any integer n, if n^2 is even, then n is even.

Proof. We'll prove the contrapositive: if n is odd, then n^2 is odd.
Let n be odd. Then $n = 2k+1$ for some integer k.
Now, $n^2 = (2k+1)^2 = 4k^2 + 4k + 1 = 2(2k^2 + 2k) + 1$
Since $2k^2 + 2k$ is an integer, n^2 is odd by definition.
Therefore, if n^2 is even, then n must be even. ∎

Problem 2

Solve the following system of equations:

$$3x + 2y = 7 \tag{64}$$
$$x - y = 1 \tag{65}$$

Solution:
From the second equation, we have $x = y + 1$. Substituting into the first equation:

$$3(y+1) + 2y = 7 \tag{66}$$
$$3y + 3 + 2y = 7 \tag{67}$$
$$5y + 3 = 7 \tag{68}$$
$$5y = 4 \tag{69}$$
$$y = \frac{4}{5} \tag{70}$$

Now we can find x:

$$x = y + 1 \tag{71}$$
$$x = \frac{4}{5} + 1 \tag{72}$$
$$x = \frac{4}{5} + \frac{5}{5} \tag{73}$$
$$x = \frac{9}{5} \tag{74}$$

Therefore, the solution is $x = \frac{9}{5}$ and $y = \frac{4}{5}$.

Problem with Multiple Parts

Problem 3

Consider the function $f(x) = x^3 - 3x + 1$.

(a) Find all critical points of f.
(b) Determine whether each critical point is a local maximum, local minimum, or neither.
(c) Find the global maximum and minimum of f on the interval $[-2, 2]$.

Solution:

(a) To find the critical points, we calculate $f'(x)$ and set it equal to zero:

$$f'(x) = 3x^2 - 3 \tag{75}$$
$$3x^2 - 3 = 0 \tag{76}$$
$$3x^2 = 3 \tag{77}$$
$$x^2 = 1 \tag{78}$$
$$x = \pm 1 \tag{79}$$

So, the critical points are $x = 1$ and $x = -1$.

(b) To determine the nature of these critical points, we compute $f''(x)$:

$$f''(x) = 6x \tag{80}$$

For $x = 1$, we have $f''(1) = 6 > 0$, so $x = 1$ is a local minimum.
For $x = -1$, we have $f''(-1) = -6 < 0$, so $x = -1$ is a local maximum.

(c) To find the global extrema on $[-2, 2]$, we evaluate f at the critical points and endpoints:

$$f(-2) = (-2)^3 - 3(-2) + 1 = -8 + 6 + 1 = -1 \tag{81}$$
$$f(-1) = (-1)^3 - 3(-1) + 1 = -1 + 3 + 1 = 3 \tag{82}$$
$$f(1) = (1)^3 - 3(1) + 1 = 1 - 3 + 1 = -1 \tag{83}$$
$$f(2) = (2)^3 - 3(2) + 1 = 8 - 6 + 1 = 3 \tag{84}$$

Therefore, the global maximum is 3, occurring at $x = -1$ and $x = 2$, and the global minimum is -1, occurring at $x = -2$ and $x = 1$.

Tip

The `enumerate` environment with the `enumitem` package gives you great flexibility in formatting lists. Use the `label` option to customize the numbering style.

Adding Figures and Diagrams

Including External Images

To include an external image, use the `\includegraphics` command:

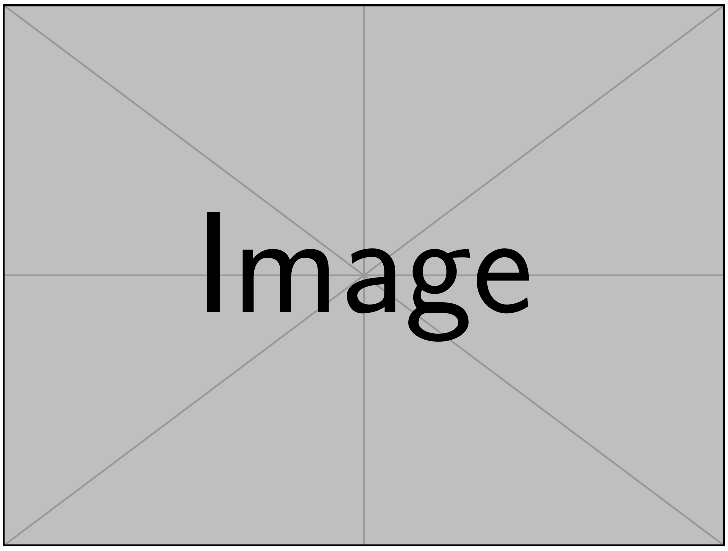

Figure 1: Example figure caption explaining the image context and significance.

You can reference figures using their labels: See Figure 1.

Note

The `example-image` is a built-in placeholder image provided by the `graphicx` package. Replace it with your actual image file.

Creating Diagrams with TikZ

TikZ is a powerful package for creating diagrams directly within LaTeX:

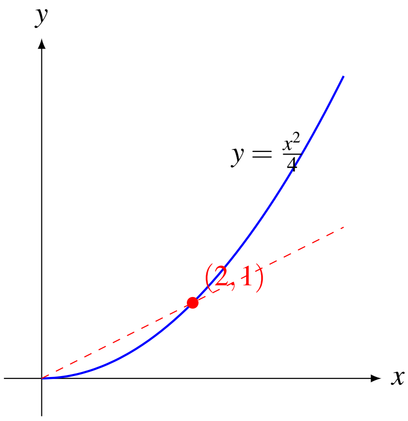

Figure 2: A parabola with its tangent line at $x = 2$.

Tip

TikZ has a steep learning curve but is extremely versatile. Start with simple diagrams and gradually explore more commands as needed.

Bibliography and Citations

In more advanced mathematics writing, you'll often need to cite references. Here's a basic example using the `thebibliography` environment:

To cite a reference in your text, use the `\cite` command:

As shown by Knuth [1], LaTeX is a powerful typesetting system for mathematics.

References

[1] Knuth, D. E. (1984). The TeXbook. Addison-Wesley.

[2] Lamport, L. (1994). LaTeX: A Document Preparation System. Addison-Wesley.

[3] Stewart, J. (2015). Calculus: Early Transcendentals. Cengage Learning.

Note

For more complex documents, consider using BibTeX or BibLaTeX for managing references.

Common Mistakes and Tips

Spacing in Math Mode

LaTeX automatically handles most spacing in mathematical expressions, but sometimes manual adjustments are needed:

- Use `\,` for a thin space: $f(x)\,dx$
- Use `\;` for a medium space: $A\;B$
- Use `\quad` for a larger space: $A\quad B$
- Use `\qquad` for an even larger space: $A\qquad B$
- Use `\!` for a negative thin space (bringing symbols closer): $\int\!\int$

Braces and Brackets

Use `\left` and `\right` to create automatically sized delimiters:

$$\left(\frac{a}{b}\right) \quad \left[\sum_{i=1}^{n} i^2\right] \quad \left\{\frac{1}{1-x}\right\} \quad \left|\frac{x}{y}\right| \quad \|\vec{v}\| \tag{85}$$

Text in Math Mode

Use `\text{}` for words within mathematical expressions:

$$f(x) = \begin{cases} x^2 & \text{if } x \geq 0 \\ -x^2 & \text{if } x < 0 \end{cases} \tag{86}$$

Warning

Never use normal text directly in math mode! Always wrap it with `\text{}` to ensure proper spacing and font consistency.

Multi-letter Variables and Functions

Standard functions should use upright font, while variables use italic:

- Correct: $\sin(x)$, $\log(y)$, $\lim_{x\to 0} f(x)$
- Incorrect: $sin(x)$, $log(y)$

Common mathematical functions have predefined commands:

- Trigonometric: `\sin`, `\cos`, `\tan`, `\csc`, `\sec`, `\cot`
- Inverse trigonometric: `\arcsin`, `\arccos`, `\arctan`
- Hyperbolic: `\sinh`, `\cosh`, `\tanh`
- Logarithmic and exponential: `\log`, `\ln`, `\exp`
- Others: `\lim`, `\max`, `\min`, `\sup`, `\inf`, `\det`, `\gcd`

For functions not predefined, use `\operatorname{name}` or define your own with `\DeclareMathOperator`.

Conclusion

This template provides a comprehensive starting point for typesetting mathematical documents using LaTeX. As you become more familiar with the system, you'll discover additional packages and commands that suit your specific needs.

Remember that learning LaTeX is an incremental process. Start with basic documents and gradually incorporate more advanced features as you become comfortable.

Tip

Practice regularly with small documents before attempting larger projects. When encountering errors, read the error messages carefully—they often provide helpful information for troubleshooting.

Note

Online resources like the LaTeX Stack Exchange (https://tex.stackexchange.com/) and the Overleaf Documentation (https://www.overleaf.com/learn) are invaluable for learning more advanced techniques and solving specific problems.