college algebra rational expressions concepts

Mastering College Algebra Rational Expressions Concepts: A Comprehensive Guide

college algebra rational expressions concepts are a fundamental building block for advanced mathematics, offering a powerful way to represent and manipulate ratios of polynomials. Understanding these expressions is not just about memorizing rules; it’s about grasping the underlying logic that allows us to simplify complex fractions, solve equations, and model real-world scenarios. This article will demystify rational expressions, breaking down their core principles, from definition and simplification to operations like addition, subtraction, multiplication, and division, and even tackling equations and inequalities involving them. We'll explore common pitfalls and provide clear, actionable strategies to build your confidence and proficiency. Prepare to unlock a deeper understanding of these essential algebraic tools.

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What are Rational Expressions?

At its heart, a rational expression is simply a fraction where the numerator and the denominator are polynomials. Think of it like a regular fraction, say 1/2, but instead of just numbers, we have algebraic expressions. So, something like $(x + 3) / (x - 1)$ is a rational expression. The key defining characteristic is that both the top and bottom parts are polynomials, which are expressions consisting of variables and coefficients, involving only the operations of addition, subtraction, multiplication, and non-negative integer exponents. It’s crucial to remember that, just like with regular fractions, the denominator of a rational expression can never be zero. This restriction is fundamental to preventing undefined values in our mathematical operations.

Consider the structure of a polynomial. It can be a single term, like $5x^2$, or a combination of terms, like $2x^3 - 7x + 4$. When we place one polynomial over another, we form a rational expression. For example, if our numerator is the polynomial $3x^2 + 5x$ and our denominator is $x - 2$, we get the rational expression $(3x^2 + 5x) / (x - 2)$. The domain of a rational expression is all real numbers except for those values of the variable that make the denominator equal to zero. Finding these excluded values is often the first step in working with any rational expression, as they represent points where the expression is undefined and thus not valid in our calculations.

Identifying Polynomials in Rational Expressions

To effectively work with rational expressions, you must first be able to identify the polynomials that comprise them. A polynomial is characterized by its terms, each of which is a constant multiplied by a variable raised to a non-negative integer power. For instance, in the expression $5x^3 - 2x + 7$, the terms are $5x^3$, $-2x$, and 7. The exponents (3, 1, and 0 for the constant term) are all non-negative integers. In contrast, an expression like $\sqrt{x}$ (which is $x^{(1/2)}$) or $1/x$ (which is $x^{(-1)}$) would not be considered polynomials in this context because of the fractional or negative exponents.

When you encounter a rational expression, such as $(4x^2 - 9) / (2x + 3)$, take a moment to analyze both the numerator and the denominator. The numerator, $4x^2 - 9$, is a polynomial because it consists of terms with non-negative integer exponents (2 and 0). Similarly, the denominator, $2x + 3$, is also a polynomial with exponents of 1 and 0. Recognizing these polynomial structures is the foundation for all subsequent manipulations and problem-solving techniques involving rational expressions in college algebra.

The Importance of the Denominator Not Being Zero

The rule that the denominator of a fraction cannot be zero is paramount in mathematics, and it holds immense significance when dealing with rational expressions. Division by zero is an undefined operation, meaning it doesn't have a valid numerical result. In the context of a rational expression, any value of the variable that causes the denominator to equal zero renders the entire expression meaningless for that specific value. Therefore, identifying these "excluded values" is a critical first step in understanding the behavior and domain of any rational expression.

For example, consider the rational expression $5 / (x - 4)$. To find the values of x that are not allowed, we set the denominator equal to zero: $x - 4 = 0$. Solving this simple equation gives us $x = 4$. This tells us that the rational expression $5 / (x - 4)$ is undefined when x is 4. For any other real number substituted for x, the expression will yield a valid result. This concept of domain restriction is vital for graphing functions, solving equations, and ensuring the integrity of our mathematical processes.

Simplifying Rational Expressions

Simplifying rational expressions is akin to reducing a regular fraction to its lowest terms. The goal is to eliminate any common factors that exist between the numerator and the denominator. This process makes the expression easier to work with, understand, and analyze, much like how reducing 4/8 to 1/2 simplifies our understanding of the quantity. The core principle here is the multiplicative identity: multiplying by 1 (in the form of a common factor divided by itself) doesn't change the value of the expression.

To achieve simplification, we employ factoring techniques. This involves breaking down both the numerator and the denominator into their prime factors. Once factored, we can visually identify and cancel out any identical factors that appear in both the top and bottom. It is absolutely essential to remember that we can only cancel factors, not terms. For instance, in the expression $(x + 2) / (x + 3)$, we cannot cancel the 'x' or the '2' and '3' because they are parts of terms, not standalone factors. However, in an expression like $(x (x + 2)) / (x (x + 3))$, we can cancel the common factor 'x'.

Factoring as the Key to Simplification

The ability to factor polynomials efficiently is the linchpin of simplifying rational expressions. Without strong factoring skills, you'll find yourself stuck when trying to reduce these algebraic fractions. You'll need to be proficient with various factoring methods, including:

- Factoring out the greatest common factor (GCF).
- Factoring difference of squares ($a^2 - b^2 = (a - b)(a + b)$).
- Factoring sum and difference of cubes ($a^3 \pm b^3$).
- Factoring trinomials (like $ax^2 + bx + c$).
- Factoring by grouping.

These techniques allow you to decompose the polynomials in the numerator and denominator into their constituent factors.

Once both the numerator and denominator are fully factored, the next step is to identify any common factors that are present in both. Let's consider an example: simplify the rational expression $(x^2 - 4) / (x^2 + 4x + 4)$. First, we factor the numerator: $x^2 - 4$ is a difference of squares, so it factors into $(x - 2)(x + 2)$. Next, we factor the denominator: $x^2 + 4x + 4$ is a perfect square trinomial, factoring into $(x + 2)(x + 2)$ or $(x + 2)^2$. Now we have $[(x - 2)(x + 2)] / [(x + 2)(x + 2)]$. We can see that $(x + 2)$ is a common factor in both the numerator and the denominator. Canceling one instance of $(x + 2)$ from the top and bottom leaves us with $(x - 2) / (x + 2)$, provided that $x \neq -2$.

Canceling Common Factors: The Golden Rule

The act of simplification boils down to canceling common factors. Remember the golden rule: you can only cancel what is a factor of both the numerator and the denominator. This means that the entire expression must be in a factored form before you even think about canceling. If you see something like $(x + 5) / (x + 2)$, you cannot cancel the 'x's, because 'x' is not a separate factor in either the numerator or the denominator; it's part of a sum. To cancel, the entire numerator would need to be a multiple of the entire denominator, or vice versa, or both would need to share a common, irreducible factor.

Let's illustrate with a slightly more complex case. Suppose we need to simplify $(6x^2 + 11x - 10) / (3x^2 - 7x + 2)$.
First, factor the numerator: $6x^2 + 11x - 10$ factors into $(2x - 5)(3x + 2)$.
Next, factor the denominator: $3x^2 - 7x + 2$ factors into $(3x - 1)(x - 2)$.
Our expression is now $[(2x - 5)(3x + 2)] / [(3x - 1)(x - 2)]$.

In this particular example, there are no common factors between the numerator and the denominator. Thus, this rational expression is already in its simplest form. This highlights the importance of thorough factoring; sometimes, after factoring, you discover there's nothing to cancel, and that's a perfectly valid outcome!

Operations with Rational Expressions

Just as we perform basic arithmetic operations on numerical fractions, we can also add, subtract, multiply, and divide rational expressions. Each operation has its own set of rules and procedures, but they all build upon the fundamental concepts of factoring and finding common denominators. Mastering these operations is crucial for solving more complex algebraic problems and understanding the behavior of rational functions.

Multiplication and division tend to be more straightforward because they don't require finding a common denominator. Addition and subtraction, on the other hand, necessitate a common denominator, making them slightly more involved but no less important. Understanding the nuances of each operation will equip you to handle any manipulation of rational expressions that comes your way in college algebra and beyond.

Multiplying Rational Expressions

Multiplying rational expressions is perhaps the most direct of the operations. The process is simple: multiply the numerators together and multiply the denominators together. However, before you perform the multiplication, it's almost always beneficial to factor each polynomial in the numerators and denominators. This allows you to cancel common factors across the multiplication, which often leads to a much simpler final expression.

The rule is: (a/b) (c/d) = (ac) / (bd). Applying this to rational expressions, let's say we have [(x^2 - 1) / (x + 3)] [(x + 3) / (x - 1)].
First, factor: (x^2 - 1) = (x - 1)(x + 1).
The expression becomes: [((x - 1)(x + 1)) / (x + 3)] [(x + 3) / (x - 1)].
Now, we can identify and cancel common factors: (x + 3) in the numerator of the second fraction and the denominator of the first, and (x - 1) in the numerator of the first fraction and the denominator of the second.
After canceling, we are left with (x + 1) / 1, which simplifies to just x + 1. This demonstrates the power of factoring before multiplying.

Dividing Rational Expressions

Dividing by a rational expression is equivalent to multiplying by its reciprocal. This means that the division operation is reduced to a multiplication problem, making it conceptually similar. To divide two rational expressions, you keep the dividend the same, change the division sign to a multiplication sign, and flip the divisor (find its reciprocal).

The rule is: $(a/b) \div (c/d) = (a/b)(d/c)$. Let's apply this to an example: $[(x^2 + 5x + 6) / (x^2 - 4)] \div [(x + 3) / (x + 2)]$.
First, we rewrite the division as multiplication by the reciprocal of the second expression: $[(x^2 + 5x + 6) / (x^2 - 4)] [(x + 2) / (x + 3)]$.
Now, we factor all polynomials:
$x^2 + 5x + 6$ factors into $(x + 2)(x + 3)$.
$x^2 - 4$ factors into $(x - 2)(x + 2)$.
Our expression becomes: $[((x + 2)(x + 3)) / ((x - 2)(x + 2))] [(x + 2) / (x + 3)]$.
We can cancel common factors: $(x + 3)$ and $(x + 2)$.
After canceling, we are left with $(x + 2) / (x - 2)$. Remember to consider any restrictions on the variables introduced by the original denominators and the flipped divisor.

Adding and Subtracting Rational Expressions

Adding and subtracting rational expressions requires a common denominator. If the denominators are already the same, you simply add or subtract the numerators and keep the common denominator. However, if the denominators are different, you must find the least common denominator (LCD) and rewrite each fraction with this new denominator before you can combine the numerators.

Finding the LCD involves identifying the least common multiple of the denominators. This usually means factoring each denominator and then taking the highest power of each unique factor present. For instance, to add $(2/x) + (3/(x+1))$, the denominators are x and $x+1$. They share no common factors, so the LCD is simply their product: $x(x+1)$. We then rewrite each fraction:
$(2/x) = [2 (x+1)] / [x (x+1)] = (2x + 2) / (x(x+1))$
$(3/(x+1)) = [3 x] / [(x+1) x] = (3x) / (x(x+1))$
Now that they have a common denominator, we can add the numerators:
$[(2x + 2) + 3x] / (x(x+1)) = (5x + 2) / (x(x+1))$.

When subtracting, the process is similar, but you must be careful with the signs. For example, to subtract $(1/(x-2)) - (3/(x+1))$:
The LCD is $(x-2)(x+1)$.
Rewrite the fractions:
$[1 (x+1)] / [(x-2)(x+1)] - [3 (x-2)] / [(x+1)(x-2)]$
$= (x + 1) / ((x-2)(x+1)) - (3x - 6) / ((x-2)(x+1))$
Now, subtract the numerators, distributing the negative sign:
$[(x + 1) - (3x - 6)] / ((x-2)(x+1))$
$= (x + 1 - 3x + 6) / ((x-2)(x+1))$
$= (-2x + 7) / ((x-2)(x+1))$.

Complex Rational Expressions

A complex rational expression, sometimes called a compound fraction, is essentially a fraction within a fraction. The numerator or the denominator (or both) of the main fraction contains one or more rational expressions itself. These can look intimidating at first glance, but they can be simplified using the principles we've already discussed for operations with rational expressions.

There are two primary methods to simplify complex rational expressions: either simplify the numerator and denominator separately into single fractions and then divide, or multiply the entire complex fraction by a form of '1' that consists of the least common denominator of all the smaller fractions within it. Both methods, when applied correctly, lead to the same simplified form, but one might feel more intuitive depending on the specific problem.

Method 1: Simplifying Numerator and Denominator

This method involves treating the numerator and the denominator of the complex fraction as separate problems. You simplify the complex numerator into a single rational expression and simplify the complex denominator into a single rational expression. Once you have a simple rational expression over another simple rational expression, you can then perform the division (which is multiplication by the reciprocal).

Let's take the example: [(1/x) + (1/y)] / [(1/x) - (1/y)].
First, simplify the numerator: (1/x) + (1/y). The LCD is xy. So, we get [(y/xy) + (x/xy)] = (y + x) / xy.
Next, simplify the denominator: (1/x) - (1/y). The LCD is also xy. So, we get [(y/xy) - (x/xy)] = (y - x) / xy.
Now, our complex fraction is [(y + x) / xy] / [(y - x) / xy].
To divide, we multiply the first fraction by the reciprocal of the second: [(y + x) / xy] [xy / (y - x)].
We can cancel the common xy terms, leaving us with (y + x) / (y - x).

Method 2: Multiplying by the LCD of Inner Fractions

This method often feels more direct and can be quicker once you get the hang of it. The idea is to identify the least common denominator of all the individual smaller fractions that appear anywhere within the complex fraction. Then, you multiply both the numerator and the denominator of the main fraction by this LCD. This clever multiplication clears out all the denominators of the smaller fractions, leaving you with a simple rational expression.

Let's use the same example: [(1/x) + (1/y)] / [(1/x) - (1/y)].
The individual fractions are 1/x and 1/y. The LCD of these is xy.
Now, multiply the entire complex fraction by xy/xy:
[{ (1/x) + (1/y) } xy] / [{ (1/x) - (1/y) } xy]
Distribute the xy to each term in the numerator and denominator:
[(1/x)xy + (1/y)xy] / [(1/x)xy - (1/y)xy]
This simplifies to:
[y + x] / [y - x]
As you can see, this method directly yields the simplified result (y + x) / (y - x).

Solving Rational Equations

Rational equations are algebraic equations that contain at least one rational expression. Solving these equations involves finding the values of the variable that make the equation true. The primary strategy for solving rational equations is to eliminate the denominators by multiplying both sides of the equation by the least common denominator (LCD) of all the rational expressions involved.

It's absolutely crucial to check your solutions after solving a rational equation. This is because the process of eliminating denominators can sometimes introduce extraneous solutions – solutions that satisfy the modified equation but not the original one. Extraneous solutions arise when a potential solution makes one of the original denominators equal to zero, which is an undefined operation.

Finding the Least Common Denominator (LCD)

The first and most critical step in solving a rational equation is to identify the least common denominator (LCD) of all the fractions present. This involves factoring each denominator completely. Once factored, the LCD is constructed by taking the highest power of every unique factor that appears in any of the denominators.

For example, consider the equation: $3/(x - 1) + 2/(x + 1) = 5/(x^2 - 1)$.
First, factor the denominators:
$x - 1$ remains $x - 1$.
$x + 1$ remains $x + 1$.
$x^2 - 1$ factors into $(x - 1)(x + 1)$.
The unique factors are $(x - 1)$ and $(x + 1)$. The highest power of each is 1.
Therefore, the LCD is $(x - 1)(x + 1)$.

Multiplying by the LCD to Eliminate Denominators

Once you have determined the LCD, you multiply both sides of the rational equation by this LCD. This action effectively cancels out all the denominators, transforming the rational equation into a simpler polynomial equation (often linear or quadratic) that you can solve using standard algebraic techniques.

Continuing with our example: $3/(x - 1) + 2/(x + 1) = 5/(x^2 - 1)$, with LCD = $(x - 1)(x + 1)$.
Multiply each term by the LCD:
$(x - 1)(x + 1) [3/(x - 1)] + (x - 1)(x + 1) [2/(x + 1)] = (x - 1)(x + 1) [5/((x - 1)(x + 1))]$
After canceling the common factors in each term:
$3(x + 1) + 2(x - 1) = 5$
Now, distribute and solve the resulting linear equation:
$3x + 3 + 2x - 2 = 5$
$5x + 1 = 5$
$5x = 4$
$x = 4/5$.

Checking for Extraneous Solutions

As mentioned, solving rational equations can sometimes lead to extraneous solutions. These are values that appear to be solutions to the simplified equation but actually make one or more of the original denominators zero. Therefore, it is absolutely essential to substitute each potential solution back into the original rational equation to verify that it does not result in division by zero and that it satisfies the equation.

In our example, we found a potential solution $x = 4/5$. We need to check if this value makes any of the original denominators zero. The denominators were $(x - 1)$, $(x + 1)$, and $(x^2 - 1)$.
If $x = 4/5$:
$x - 1 = 4/5 - 1 = -1/5$ (not zero)
$x + 1 = 4/5 + 1 = 9/5$ (not zero)
$x^2 - 1 = (4/5)^2 - 1 = 16/25 - 1 = -9/25$ (not zero)
Since none of the denominators are zero when $x = 4/5$, this solution is valid. If, for instance, we had a solution that resulted in a denominator of zero, we would discard it as extraneous.

Solving Rational Inequalities

Rational inequalities are inequalities that involve rational expressions. Solving them requires a different approach than solving rational equations because we are looking for a range of values that satisfy the inequality, not just specific points. The core idea is to find the critical values that make the numerator or denominator equal to zero and then test intervals determined by these critical values.

The goal is to get all terms on one side of the inequality, leaving zero on the other side, and then combine the terms into a single rational expression. The critical values are then used to divide the number line into intervals, and we test a value from each interval to see if it satisfies the inequality.

Finding Critical Values

Critical values for rational inequalities are the values of the variable that make the numerator of the single rational expression equal to zero or make the denominator equal to zero. These values are critical because they are the points where the rational expression might change its sign (from positive to negative, or vice versa). The denominator critical values are always excluded from the solution set because they result in an undefined expression.

Consider the inequality: $(x + 2) / (x - 3) < 0$.
To find the critical values:
Set the numerator equal to zero: $x + 2 = 0 \Rightarrow x = -2$.
Set the denominator equal to zero: $x - 3 = 0 \Rightarrow x = 3$.
Our critical values are -2 and 3. These divide the number line into three intervals: $(-\infty, -2)$, $(-2, 3)$, and $(3, \infty)$.

Testing Intervals

Once you have identified the critical values and divided the number line into intervals, you need to test a value from each interval to determine if it satisfies the original inequality. Pick any number within an interval and substitute it into the rational expression. If the result makes the inequality true, then the entire interval is part of the solution. If it makes the inequality false, that interval is not part of the solution.

For our example $(x + 2) / (x - 3) < 0$:
Interval 1: $(-\infty, -2)$. Let's test $x = -3$.
$(-3 + 2) / (-3 - 3) = -1 / -6 = 1/6$. Is $1/6 < 0$? No, it's false.
Interval 2: $(-2, 3)$. Let's test $x = 0$.
$(0 + 2) / (0 - 3) = 2 / -3 = -2/3$. Is $-2/3 < 0$? Yes, it's true.
Interval 3: $(3, \infty)$. Let's test $x = 4$.
$(4 + 2) / (4 - 3) = 6 / 1 = 6$. Is $6 < 0$? No, it's false.
So, the solution is the interval where the inequality was true, which is $(-2, 3)$.

Writing the Solution Set

The final step in solving a rational inequality is to write the solution set clearly, using interval notation or set-builder notation. Remember that values that make the denominator zero are never included in the solution set, so they will always be represented with parentheses in interval notation. Values that make the numerator zero may be included if the inequality sign is inclusive ($\leq$ or $\geq$), but not if it is strict ($<$ or $>$).

In our previous example, $(x + 2) / (x - 3) < 0$, the critical value $x = 3$ made the denominator zero, so it's excluded. The critical value $x = -2$ made the numerator zero. Since the inequality is strict ($<$), $x = -2$ is also excluded. Therefore, the solution set is all numbers between -2 and 3, not including -2 or 3. In interval notation, this is written as $(-2, 3)$. If the inequality had been $(x + 2) / (x - 3) \leq 0$, then $x = -2$ would have been included, and the solution would have been $[-2, 3)$.

Applications of Rational Expressions

Rational expressions aren't just abstract mathematical constructs; they have practical applications in various fields, helping us model and solve real-world problems. From physics and engineering to economics and biology, the ability to represent relationships using ratios of polynomials provides a powerful analytical tool.

One common area where rational expressions appear is in problems involving rates of work, distances, or mixtures. They allow us to set up equations that describe how different quantities interact and change over time or under varying conditions. Understanding these applications can make the abstract concepts of college algebra feel much more concrete and relevant.

Work Rate Problems

Work rate problems often utilize rational expressions to describe how long it takes for multiple individuals or machines to complete a task, especially when they work at different speeds. If a person can complete a job in 't' hours, their rate of work is 1/t jobs per hour. When multiple workers collaborate, their rates add up.

For example, if Alice can paint a room in 4 hours, her rate is 1/4 room per hour. If Bob can paint the same room in 6 hours, his rate is 1/6 room per hour. To find out how long it takes them to paint the room together, we add their rates: 1/4 + 1/6. The LCD is 12. So, (3/12) + (2/12) = 5/12 rooms per hour. If their combined rate is 5/12 rooms per hour, the time it takes them to complete one whole room is the reciprocal of this rate, which is 12/5 hours. This type of problem is solved using rational expressions.

Distance, Rate, and Time Problems

Problems involving distance, rate, and time are another classic application where rational expressions frequently appear, particularly when dealing with relative speeds or scenarios where the rate is not constant. The fundamental relationship is distance = rate × time (d = rt), which can be rearranged to time = distance / rate (t = d/r) or rate = distance / time (r = d/t).

Consider a scenario where a boat travels downstream and then upstream. The speed downstream is its speed in still water plus the speed of the current, while the speed upstream is its speed in still water minus the speed of the current. If the distance traveled in each direction is the same, the time taken for each leg of the journey will be represented by a rational expression, and problems may involve setting these times equal or finding a total time.

For instance, if a boat travels 20 miles downstream at a speed of (v + c) mph (where v is boat speed and c is current speed) and then 20 miles upstream at a speed of (v - c) mph, the time taken for the downstream journey is 20/(v + c) hours, and the time for the upstream journey is 20/(v - c) hours. Summing these to find the total travel time results in a rational expression: 20/(v + c) + 20/(v - c). Solving for v or c or the total time would involve manipulating this rational expression.

Rational expressions are a cornerstone of college algebra, providing the tools to simplify, manipulate, and solve a wide array of mathematical problems. By mastering the concepts of factoring, finding common denominators, and understanding the restrictions on variables, you can confidently tackle any challenge involving these fundamental algebraic components. The ability to work with rational expressions opens doors to understanding more complex mathematical functions and their applications in the real world, making it a truly rewarding area of study.

FAQ

Q: What is the most common mistake students make when simplifying rational expressions?

A: The most common mistake students make when simplifying rational expressions is canceling terms instead of factors. For example, they might incorrectly cancel the 'x' in (x+5)/(x+2) to get 5/2. You can only cancel common factors that are multiplied together, not terms that are added or subtracted.

Q: Why is it important to check for extraneous solutions in rational equations?

A: It's crucial to check for extraneous solutions because the process of multiplying rational equations by the least common denominator (LCD) can sometimes introduce solutions that satisfy the manipulated equation but not the original one. These extraneous solutions arise when a potential solution makes any of the original denominators equal to zero, which is an undefined operation.

Q: What is the difference between a complex rational expression and a rational expression?

A: A rational expression is a fraction where the numerator and denominator are polynomials. A complex rational expression is a fraction where the numerator or denominator (or both) are themselves rational expressions. Think of it as a "fraction within a fraction."

Q: Can rational expressions be used to model real-world phenomena?

A: Absolutely! Rational expressions are used in various applications, including work-rate problems (how long it takes for multiple people or machines to complete a task), distance, rate, and time problems (especially with relative speeds or currents), and in physics and engineering for modeling physical relationships.

Q: What are the critical values in a rational inequality, and why are they important?

A: Critical values in a rational inequality are the values of the variable that make the numerator of the combined rational expression equal to zero or make the denominator equal to zero. These values are crucial because they mark the points where the sign of the rational expression can change, and they are used to divide the number line into intervals that are then tested to find the solution set.

Q: When adding or subtracting rational expressions with different denominators, what is the first step?

A: The first step when adding or subtracting rational expressions with different denominators is to find a common denominator, specifically the least common denominator (LCD). This allows you to rewrite each expression with the same denominator so that the numerators can be added or subtracted.

Q: How do you know when a rational expression is in its simplest form?

A: A rational expression is in its simplest form when the numerator and the denominator have no common factors other than 1 and -1. This means you have completely factored both the numerator and the denominator and canceled out all identical factors.

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