

Prove each of the following statements by induction.

1. For all natural numbers n ,

a) $1 + 2 + 3 + \dots + n = \frac{n(n+1)}{2}.$

b) $1^2 + 2^2 + 3^2 + \dots + n^2 = \frac{n(n+1)(2n+1)}{6}.$

c) $1^3 + 2^3 + 3^3 + \dots + n^3 = \frac{n^2(n+1)^2}{4}.$

2. For all natural numbers n , $\frac{1}{1 \cdot 2} + \frac{1}{2 \cdot 3} + \frac{1}{3 \cdot 4} + \dots + \frac{1}{n(n+1)} = \frac{n}{n+1}.$

3. For all natural numbers n , $1 \cdot 2 + 2 \cdot 2^2 + 3 \cdot 2^3 + 4 \cdot 2^4 + \dots + n \cdot 2^n = 2(1 + (n-1)2^n).$

4. For all natural numbers $n \geq 5$, $2^n \geq n^2.$

5. Prove that for all natural number n , 10^n can be written as a sum of two perfect squares.

6. Recall (F_n) is the Fibonacci sequence, defined as

$$F_1 = 1, \quad F_2 = 1, \quad \text{and} \quad F_{n+2} = F_n + F_{n+1}$$

Prove each of the following statements for all natural numbers n .

a) $F_1 + F_2 + F_3 + \dots + F_n = F_{n+2} - 1$

b) $F_1^2 + F_2^2 + F_3^2 + \dots + F_n^2 = F_n F_{n+1}$

c) $F_1 + F_3 + \dots + F_{2n-1} = F_{2n}$

d) $F_2 + F_4 + \dots + F_{2n} = F_{2n+1} - 1$

e) For all $n \geq 2$, $F_n^2 - F_{n-1} \cdot F_{n+1} = (-1)^{n-1}$

7. Prove that for all natural number n , $11^n - 6$ is divisible by 5.

8. Prove that for all natural number n , $2^{3n} - 3^n$ is divisible by 5.

9. Prove that for all natural number n , $2^{2n} + 24n - 10$ is divisible by 18.

Sample Problems - Solutions

1. a) For all natural numbers n , $1 + 2 + 3 + \dots + n = \frac{n(n+1)}{2}$.

Proof:

Part 1: We check for the first few values of n .

If $n = 1$, then

$$\text{LHS} = 1 = 1 \quad \text{and} \quad \text{RHS} = \frac{1(1+1)}{2} = \frac{2}{2} = 1$$

If $n = 2$, then

$$\text{LHS} = 1 + 2 = 3 \quad \text{and} \quad \text{RHS} = \frac{2(2+1)}{2} = \frac{6}{2} = 3$$

If $n = 3$, then

$$\text{LHS} = 1 + 2 + 3 = 6 \quad \text{and} \quad \text{RHS} = \frac{3(3+1)}{2} = \frac{12}{2} = 6$$

So the statement is true for $n = 1, 2$ and 3 .

Part 2. Suppose that k is a positive integer for which

$$1 + 2 + 3 + \dots + k = \frac{k(k+1)}{2} \quad \text{This is the inductive hypothesis}$$

Let us add $k + 1$ to both sides. The left-hand side becomes

$$1 + 2 + 3 + \dots + k + (k + 1)$$

and the right hand side becomes

$$\begin{aligned} \text{RHS} &= \frac{k(k+1)}{2} + (k+1) = \frac{k(k+1)}{2} + \frac{2(k+1)}{2} = \frac{k(k+1) + 2(k+1)}{2} \\ &= \frac{k^2 + k + 2k + 2}{2} = \frac{k^2 + 3k + 2}{2} = \frac{(k+1)(k+2)}{2} = \frac{(k+1)((k+1)+1)}{2} \end{aligned}$$

So we have proved that for all positive integers k , if

$$1 + 2 + 3 + \dots + k = \frac{k(k+1)}{2} \quad \text{is true}$$

then

$$1 + 2 + 3 + \dots + k + (k + 1) = \frac{(k+1)((k+1)+1)}{2}$$

which completes our proof.

b) For all natural numbers n , $1^2 + 2^2 + 3^2 + \dots + n^2 = \frac{n(n+1)(2n+1)}{6}$.

Proof:

Part 1: We check for the first few values of n .

If $n = 1$, then

$$\text{LHS} = 1^2 = 1 \quad \text{and} \quad \text{RHS} = \frac{1(1+1)(2 \cdot 1 + 1)}{6} = \frac{6}{6} = 1$$

If $n = 2$, then

$$\text{LHS} = 1^2 + 2^2 = 5 \quad \text{and} \quad \text{RHS} = \frac{2(2+1)(2 \cdot 2 + 1)}{6} = \frac{30}{6} = 5$$

If $n = 3$, then

$$\text{LHS} = 1^2 + 2^2 + 3^2 = 14 \quad \text{and} \quad \text{RHS} = \frac{3(3+1)(2 \cdot 3 + 1)}{6} = \frac{84}{6} = 14$$

So the statement is true for $n = 1, 2$ and 3 .

Part 2. Suppose that k is a positive integer for which

$$1^2 + 2^2 + 3^2 + \dots + k^2 = \frac{k(k+1)(2k+1)}{6} \quad \text{This is the inductive hypothesis}$$

Let us add $(k+1)^2$ to both sides. The left-hand side becomes

$$1^2 + 2^2 + 3^2 + \dots + k^2 + (k+1)^2$$

and the right hand side becomes

$$\text{RHS} = \frac{k(k+1)(2k+1)}{6} + (k+1)^2 = \frac{k(k+1)(2k+1)}{6} + \frac{6(k+1)^2}{6}$$

We factor out $\frac{k+1}{6}$

$$\begin{aligned} \text{RHS} &= \frac{k(k+1)(2k+1)}{6} + \frac{6(k+1)^2}{6} = \frac{k+1}{6} (k(2k+1) + 6(k+1)) \\ &= \frac{k+1}{6} (2k^2 + k + 6k + 6) = \frac{k+1}{6} (2k^2 + 7k + 6) \end{aligned}$$

and so happens $2k^2 + 7k + 6$ factors as $(k+2)(2k+3)$. So we have

$$\begin{aligned} \text{RHS} &= \frac{k+1}{6} (2k^2 + 7k + 6) = \frac{k+1}{6} (k+2)(2k+3) = \frac{(k+1)(k+2)(2k+3)}{6} \\ &= \frac{(k+1)((k+1)+1)(2(k+1)+1)}{6} \end{aligned}$$

So we have proved that for all positive integers k , if

$$1^2 + 2^2 + 3^2 + \dots + k^2 = \frac{k(k+1)(2k+1)}{6}$$

then

$$1^2 + 2^2 + 3^2 + \dots + k^2 + (k+1)^2 = \frac{(k+1)((k+1)+1)(2(k+1)+1)}{6}$$

which completes our proof.

c) For all natural numbers n , $1^3 + 2^3 + 3^3 + \dots + n^3 = \frac{n^2(n+1)^2}{4}$

Proof:

Part 1: We check for the first few values of n .

If $n = 1$, then

$$\text{LHS} = 1^3 = 1 \quad \text{and} \quad \text{RHS} = \frac{1^2(1+1)^2}{4} = \frac{4}{4} = 1$$

If $n = 2$, then

$$\text{LHS} = 1^3 + 2^3 = 9 \quad \text{and} \quad \text{RHS} = \frac{2^2(2+1)^2}{4} = \frac{36}{4} = 9$$

If $n = 3$, then

$$\text{LHS} = 1^3 + 2^3 + 3^3 = 36 \quad \text{and} \quad \text{RHS} = \frac{3^2(3+1)^2}{4} = \frac{144}{4} = 36$$

So the statement is true for $n = 1, 2$ and 3 .

Part 2. Suppose that k is a positive integer for which

$$1^3 + 2^3 + 3^3 + \dots + k^3 = \frac{k^2(k+1)^2}{4} \quad \text{This is the inductive hypothesis}$$

Let us add $(k+1)^3$ to both sides. The left-hand side becomes

$$1^3 + 2^3 + 3^3 + \dots + k^3 + (k+1)^3$$

and the right hand side becomes

$$\begin{aligned} \text{RHS} &= \frac{k^2(k+1)^2}{4} + (k+1)^3 = \frac{k^2(k+1)^2}{4} + \frac{4(k+1)^3}{4} \quad \text{factor out } \frac{(k+1)^2}{4} \\ &= \frac{(k+1)^2}{4} (k^2 + 4(k+1)) = \frac{(k+1)^2}{4} (k^2 + 4k + 4) = \frac{(k+1)^2}{4} (k+2)^2 = \frac{(k+1)^2(k+1+1)^2}{4} \end{aligned}$$

So we have proved that for all positive integers k , if

$$1^3 + 2^3 + 3^3 + \dots + k^3 = \frac{k^2(k+1)^2}{4} \quad \text{is true}$$

then

$$1^3 + 2^3 + 3^3 + \dots + k^3 + (k+1)^3 = \frac{(k+1)^2((k+1)+1)^2}{4}$$

which completes our proof.

2. For all natural numbers n , $\frac{1}{1 \cdot 2} + \frac{1}{2 \cdot 3} + \frac{1}{3 \cdot 4} + \dots + \frac{1}{n(n+1)} = \frac{n}{n+1}$.

Proof: Induction on n .

Part 1. If $n = 1$, then

$$\text{LHS} = \frac{1}{1 \cdot 2} = \frac{1}{2} \quad \text{and} \quad \text{RHS} = \frac{1}{1+1} = \frac{1}{2}$$

If $n = 2$, then

$$\text{LHS} = \frac{1}{1 \cdot 2} + \frac{1}{2 \cdot 3} = \frac{1}{2} + \frac{1}{6} = \frac{2}{3} \quad \text{and} \quad \text{RHS} = \frac{2}{2+1} = \frac{2}{3}$$

Part 2. Suppose that k is a natural number such that

$$\frac{1}{1 \cdot 2} + \frac{1}{2 \cdot 3} + \frac{1}{3 \cdot 4} + \dots + \frac{1}{k(k+1)} = \frac{k}{k+1} \quad (\text{Induction hypothesis})$$

We will add $\frac{1}{(k+1)(k+1+1)} = \frac{1}{(k+1)(k+2)}$ to both sides.

$$\frac{1}{1 \cdot 2} + \frac{1}{2 \cdot 3} + \frac{1}{3 \cdot 4} + \dots + \frac{1}{k(k+1)} + \frac{1}{(k+1)(k+2)} = \frac{k}{k+1} + \frac{1}{(k+1)(k+2)}$$

Let us simplify the right hand side

$$\begin{aligned} \frac{k}{k+1} + \frac{1}{(k+1)(k+2)} &= \frac{k(k+2)}{(k+1)(k+2)} + \frac{1}{(k+1)(k+2)} = \frac{k(k+2)+1}{(k+1)(k+2)} \\ &= \frac{k^2+2k+1}{(k+1)(k+2)} = \frac{(k+1)^2}{(k+1)(k+2)} = \frac{k+1}{k+2} \end{aligned}$$

Thus we have that from the induction hypotheses

$$\frac{1}{1 \cdot 2} + \frac{1}{2 \cdot 3} + \frac{1}{3 \cdot 4} + \dots + \frac{1}{k(k+1)} = \frac{k}{k+1}$$

the statement

$$\frac{1}{1 \cdot 2} + \frac{1}{2 \cdot 3} + \frac{1}{3 \cdot 4} + \dots + \frac{1}{(k+1)(k+2)} = \frac{k+1}{k+2}$$

follows. This completes our proof.

3. For all natural numbers n , $1 \cdot 2 + 2 \cdot 2^2 + 3 \cdot 2^3 + 4 \cdot 2^4 + \dots + n \cdot 2^n = 2(1 + (n-1)2^n)$.

Proof:

Part 1. If $n = 1$, then

$$\text{LHS} = 1 \cdot 2 = 2 \quad \text{and} \quad \text{RHS} = 2(1 + (1-1)2^1) = 2 \cdot 1 = 2$$

If $n = 2$, then

$$\text{LHS} = 1 \cdot 2 + 2 \cdot 2^2 = 10 \quad \text{and} \quad \text{RHS} = 2(1 + (2-1)2^2) = 2 \cdot 5 = 10$$

Part 2. Suppose that k is a natural number such that

$$1 \cdot 2 + 2 \cdot 2^2 + 3 \cdot 2^3 + 4 \cdot 2^4 + \dots + k \cdot 2^k = 2(1 + (k-1)2^k) \quad (\text{Induction hypothesis})$$

Let us add $(k+1)2^{k+1}$ to both sides. The left-hand side becomes

$$\text{LHS} = 1 \cdot 2 + 2 \cdot 2^2 + 3 \cdot 2^3 + 4 \cdot 2^4 + \dots + k \cdot 2^k + (k+1)2^{k+1}$$

and the right-hand side becomes

$$\begin{aligned}
 \text{RHS} &= 2 \left(1 + (k-1)2^k \right) + (k+1)2^{k+1} = 2 \left(1 + (k-1)2^k \right) + (k+1)2^k \cdot 2 \quad \text{factor out 2} \\
 &= 2 \left(1 + (k-1)2^k + (k+1)2^k \right) = 2 \left(1 + k2^k - 2^k + k2^k + 2^k \right) = \\
 &= 2 \left(1 + 2k2^k \right) = 2 \left(1 + k2^{k+1} \right)
 \end{aligned}$$

which completes our proof.

4. For all natural numbers $n \geq 5$, $2^n \geq n^2$

Note: this is a very interesting example illustrating how induction works, how we need both parts to work together to form a logically sound proof. The statement seems to be true immediately at $n = 1$ but then surprisingly, it will be false for a few values of n .

Proof:

Part 1. If $n = 1$, then

$$\text{LHS} = 2^1 = 2 \quad \text{and} \quad \text{RHS} = 1^2 = 1 \quad \text{and} \quad 2 > 1 \quad \text{is true}$$

If $n = 2$, then

$$\text{LHS} = 2^2 = 4 \quad \text{and} \quad \text{RHS} = 2^2 = 4 \quad \text{and} \quad 4 > 4 \quad \text{is false!}$$

If $n = 3$, then

$$\text{LHS} = 2^3 = 8 \quad \text{and} \quad \text{RHS} = 3^2 = 9 \quad \text{and} \quad 8 > 9 \quad \text{is false!}$$

If $n = 4$, then

$$\text{LHS} = 2^4 = 16 \quad \text{and} \quad \text{RHS} = 4^2 = 16 \quad \text{and} \quad 16 > 16 \quad \text{is false!}$$

If $n = 5$, then

$$\text{LHS} = 2^5 = 32 \quad \text{and} \quad \text{RHS} = 5^2 = 25 \quad \text{and} \quad 32 > 25 \quad \text{is true}$$

If $n = 6$, then

$$\text{LHS} = 2^6 = 64 \quad \text{and} \quad \text{RHS} = 6^2 = 36 \quad \text{and} \quad 64 > 36 \quad \text{is true}$$

At this point we have a sense that the statement will stay true because the left-hand side doubles when we go from k to $k+1$ while the right-hand side just increases from k^2 to $(k+1)^2$. The proof in part 2 will formalize this idea, that between the two types of growth, doubling is much 'faster'.

All we need to show is that moving from k^2 to $(k+1)^2$ is a smaller increment than doubling. In short, that

$$\begin{aligned}
 (k+1)^2 &< 2k^2 \\
 k^2 + 2k + 1 &< 2k^2 \quad \text{subtract } k^2 \\
 2k + 1 &< k^2
 \end{aligned}$$

This should be easy to prove for most positive integers. We can either solve the quadratic inequality or be a little bit sloppy or generous and say that if k is greater than 1, then

$$\begin{aligned}
 1 &< k && \text{add } 2k \\
 2k + 1 &< 2k + k \\
 2k + 1 &< 3k
 \end{aligned}$$

and if k is greater than 3, then

$$\begin{aligned}
 3 &< k && \text{multiply by } k > 0 \\
 3k &< k^2
 \end{aligned}$$

In short, if $k > 3$, then $2k + 1 < 3k < k^2$ and so

$$\begin{aligned} 2k + 1 &< k^2 && \text{add } k^2 \text{ to both sides} \\ k^2 + 2k + 1 &< 2k^2 \\ (k + 1)^2 &< 2k^2 \end{aligned}$$

This will be the core of the proof in part 2.

Part 2. Suppose that k is a natural number such that

$$2^k > k^2 \quad (\text{Induction hypothesis})$$

Let us multiply both sides by 2. The left-hand side becomes

$$\text{LHS} = 2 \cdot 2^k = 2^{k+1}$$

and the right-hand side becomes

$$\text{RHS} = 2k^2$$

So we have

$$\begin{aligned} 2^k &> k^2 \\ 2^{k+1} &> 2k^2 \end{aligned}$$

If $k > 3$, then

$$2^{k+1} > 2k^2 = k^2 + k^2 > k^2 + 3k > k^2 + 2k + 1 = (k + 1)^2$$

and so we have that if $2^k > k^2$ is true AND $k > 3$, then $2^{k+1} > (k + 1)^2$.

So we could easily prove the 'inheritance' property for all integers greater than 3 but the statement itself is NOT true for $n = 3$. Both components of the proof work together starting at $n = 5$.

	statement	inheritance to the next number
$n = 1$	true	false
$n = 2$	false	false
$n = 3$	false	true (but we didn't prove it)
$n = 4$	false	true
$n = 5$	true	true

This table illustrates why induction only works here for $n \geq 5$.

5. Prove that for all natural number n , 10^n can be written as a sum of two perfect squares.

Proof: Part 1:

$$\begin{aligned} n = 1 : & \quad 10^1 = 10 = 9 + 1 = 3^2 + 1^2 \quad \checkmark \\ n = 2 : & \quad 10^2 = 100 = 64 + 36 = 8^2 + 6^2 \quad \checkmark \\ n = 3 : & \quad 10^3 = 1000 = 900 + 100 = 30^2 + 10^2 \quad \checkmark \\ n = 4 : & \quad 10^4 = 10\,000 = 6400 + 3600 = 80^2 + 60^2 \quad \checkmark \end{aligned}$$

This problem illustrates that it is worth looking at the first part beyond $n = 1$ because it often helps us discover how the second part goes. In this case, the 'inheritance' property is from n to $n + 2$.

Part 2. Suppose that k is a natural number such that $10^k = a^2 + b^2$ for some integers a and b . Consider now 10^{k+2} .

$$10^{k+2} = 10^k \cdot 10^2 = 100 \cdot 10^k = 100(a^2 + b^2) = 100a^2 + 100b^2 = (10a)^2 + (10b)^2$$

So, if the statement is true for n , then it is also true for $n + 2$.

$$1 \Rightarrow 3 \Rightarrow 5 \Rightarrow 7 \Rightarrow 9 \Rightarrow 11 \Rightarrow 13 \dots \text{ and } 2 \Rightarrow 4 \Rightarrow 6 \Rightarrow 8 \Rightarrow 10 \Rightarrow 12 \dots$$

This completes our proof.

6. Recall (F_n) is the Fibonacci sequence, defined as $1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, \dots$

$$F_1 = 1, \quad F_2 = 1, \quad \text{and} \quad F_{n+2} = F_n + F_{n+1}$$

Prove each of the following statements for all natural numbers n .

a) $F_1 + F_2 + F_3 + \dots + F_n = F_{n+2} - 1$

Proof: Let us first label the terms of the sequence.

$$\begin{array}{cccccccccccc} 1 & 1 & 2 & 3 & 5 & 8 & 13 & 21 & 34 & 55 & 89 \\ F_1 & F_2 & F_3 & F_4 & F_5 & F_6 & F_7 & F_8 & F_9 & F_{10} & F_{11} \end{array}$$

Part 1. $n = 1$: $F_1 = F_3 - 1 \iff 1 = 2 - 1 \quad 1 = 1\checkmark$

$n = 2$: $F_1 + F_2 = F_4 - 1 \iff 1 + 1 = 3 - 1 \quad 2 = 2\checkmark$

$n = 3$: $F_1 + F_2 + F_3 = F_6 - 1 \iff 1 + 1 + 2 = 5 - 1 \quad 4 = 4\checkmark$

$n = 4$: $F_1 + F_2 + F_3 + F_4 = F_8 - 1 \iff 1 + 1 + 2 + 3 = 8 - 1 \quad 7 = 7\checkmark$

Part 2. IH. Suppose that k is a natural number such that $F_1 + F_2 + F_3 + \dots + F_k = F_{k+2} - 1$. To move to the next integer, we add F_{k+1} to both sides.

$$\begin{array}{llll} F_1 + F_2 + F_3 + \dots + F_k & = & F_{k+2} - 1 & \text{add } F_{k+1} \\ F_1 + F_2 + F_3 + \dots + F_k + F_{k+1} & = & F_{k+2} - 1 + F_{k+1} & F_{k+1} + F_{k+2} = F_{k+3} \\ F_1 + F_2 + F_3 + \dots + F_k + F_{k+1} & = & F_{k+3} - 1 & \\ F_1 + F_2 + F_3 + \dots + F_k + F_{k+1} & = & F_{(k+1)+2} - 1 & \end{array}$$

Therefore, if the statement is true for k , then it is also true for $k + 1$. This completes our proof.

b) $F_1^2 + F_2^2 + F_3^2 + \dots + F_n^2 = F_n F_{n+1}$

Proof:

Part 1. $n = 1$: $F_1^2 = 1^2 = 1$ and $F_1 F_2 = 1 \cdot 1 \quad 1 = 1\checkmark$

$n = 2$: $F_1^2 + F_2^2 = 1^2 + 1^2 = 2$ and $F_2 F_3 = 1 \cdot 2 \quad 2 = 2\checkmark$

$n = 3$: $F_1^2 + F_2^2 + F_3^2 = 1^2 + 1^2 + 2^2 = 6$ and $F_3 F_4 = 2 \cdot 3 = 6 \quad 6 = 6\checkmark$

$n = 4$: $F_1^2 + F_2^2 + F_3^2 + F_4^2 = 1^2 + 1^2 + 2^2 + 3^2 = 15$ and $F_4 F_5 = 3 \cdot 5 = 15 \quad 15 = 15\checkmark$

Part 2. IH. Suppose that k is a natural number such that $F_1^2 + F_2^2 + F_3^2 + \dots + F_k^2 = F_k F_{k+1}$. To move to the next integer, we add F_{k+1}^2 to both sides.

$$\begin{array}{llll} F_1^2 + F_2^2 + F_3^2 + \dots + F_k^2 & = & F_k F_{k+1} & \text{add } F_{k+1}^2 \\ F_1^2 + F_2^2 + F_3^2 + \dots + F_k^2 + F_{k+1}^2 & = & F_k F_{k+1} + F_{k+1}^2 & \\ & = & F_{k+1} (F_k + F_{k+1}) & F_k + F_{k+1} = F_{k+2} \\ & = & F_{k+1} F_{k+2} = F_{k+1} F_{(k+1)+1} & \end{array}$$

Therefore, if the statement is true for k , then it is also true for $k + 1$. This completes our proof.

c) $F_1 + F_3 + \dots + F_{2n-1} = F_{2n}$

Part 1. $n = 1$: $F_1 = 1$ and $F_2 = 1$ $1 = 1\checkmark$

$n = 2$: $F_1 + F_3 = 1 + 2 = 3$ and $F_4 = 3$ $3 = 3\checkmark$

$n = 3$: $F_1 + F_3 + F_5 = 1 + 2 + 5 = 8$ and $F_6 = 8$ $8 = 8\checkmark$

$n = 4$: $F_1 + F_3 + F_5 + F_7 = 1 + 2 + 5 + 13 = 21$ and $F_8 = 21$ $21 = 21\checkmark$

Part 2. IH. Suppose that k is a natural number such that $F_1 + F_3 + \dots + F_{2k-1} = F_{2k}$. To move to the next integer, we add F_{2k+1} to both sides.

$$\begin{aligned} F_1 + F_3 + \dots + F_{2k-1} &= F_{2k} && \text{add } F_{2k+1} \\ F_1 + F_3 + \dots + F_{2k-1} + F_{2k+1} &= F_{2k} + F_{2k+1} = F_{2k+2} \end{aligned}$$

This is the same as

$$F_1 + F_3 + \dots + F_{2k-1} + F_{2(k+1)-1} = F_{2(k+1)}$$

Therefore, if the statement is true for k , then it is also true for $k + 1$. This completes our proof.

d) $F_2 + F_4 + \dots + F_{2n} = F_{2n+1} - 1$

Part 1. $n = 1$ $F_2 = 1$ and $F_3 - 1 = 2 - 1$ $1 = 1\checkmark$

$n = 2$ $F_2 + F_4 = 1 + 3 = 4$ and $F_5 - 1 = 5 - 1$ $3 = 3\checkmark$

$n = 3$ $F_2 + F_4 + F_6 = 1 + 3 + 8 = 12$ and $F_7 - 1 = 13 - 1$ $12 = 12\checkmark$

$n = 4$ $F_2 + F_4 + F_6 + F_8 = 1 + 3 + 8 + 21 = 33$ and $F_9 - 1 = 34 - 1$ $33 = 33\checkmark$

Part 2. IH. Suppose that k is a natural number such that $F_2 + F_4 + \dots + F_{2k} = F_{2k+1} - 1$. To move to the next integer, we add F_{2k+2} to both sides.

$$\begin{aligned} F_2 + F_4 + \dots + F_{2k} &= F_{2k+1} - 1 && \text{add } F_{2k+2} \\ F_2 + F_4 + \dots + F_{2k} + F_{2k+2} &= F_{2k+1} - 1 + F_{2k+2} \\ &= F_{2k+1} + F_{2k+2} - 1 && F_{2k+1} + F_{2k+2} = F_{2k+3} \\ &= F_{2k+3} - 1 \end{aligned}$$

This is the same as $F_2 + F_4 + \dots + F_{2k} + F_{2(k+1)} = F_{2(k+1)+1} - 1$

Therefore, if the statement is true for k , then it is also true for $k + 1$. This completes our proof.

e) For all $n \geq 2$, $F_n^2 - F_{n-1} \cdot F_{n+1} = (-1)^{n-1}$

Part 1. $n = 2$: $F_2^2 - F_1 \cdot F_3 = 1^2 - 1 \cdot 2 = 1 - 2 = -1$ and $(-1)^1 = -1$ $-1 = -1\checkmark$

$n = 3$: $F_3^2 - F_2 \cdot F_4 = 2^2 - 1 \cdot 3 = 4 - 3 = 1$ and $(-1)^2 = 1$ $1 = 1\checkmark$

$n = 4$: $F_4^2 - F_3 \cdot F_5 = 3^2 - 2 \cdot 5 = 9 - 10 = -1$ and $(-1)^3 = -1$ $-1 = -1\checkmark$

$n = 5$: $F_5^2 - F_4 \cdot F_6 = 5^2 - 3 \cdot 8 = 25 - 24 = 1$ and $(-1)^4 = 1$ $1 = 1\checkmark$

Part 2. IH. The right-hand side is 1 for $n = 1, 3, 5, 7, \dots$ and -1 for $n = 2, 4, 6, 8, \dots$. For this reason, we would prove the inheritance property if we could show that the left-hand sides in case of k and $k + 1$ are opposites of each other.

$$F_{k+1}^2 - F_k F_{k+2} = -(F_k^2 - F_{k-1} F_{k+1})$$

Let's try. We start with $F_{k+1}^2 - F_k F_{k+2}$. We will re-write F_{k+2} as $F_k + F_{k+1}$

$$\begin{aligned} F_{k+1}^2 - F_k F_{k+2} &= F_{k+1}^2 - F_k (F_k + F_{k+1}) && \text{distribute } F_k \\ &= F_{k+1}^2 - F_k^2 - F_k F_{k+1} && \text{swap terms} \\ &= -F_k^2 + F_{k+1}^2 - F_k F_{k+1} && \text{factor out } F_{k+1} \\ &= -F_k^2 + F_{k+1} (F_{k+1} - F_k) && F_{k+1} - F_k = F_{k-1} \\ &= -F_k^2 + F_{k+1} F_{k-1} = -(F_k^2 - F_{k-1} F_{k+1}) \end{aligned}$$

Therefore, if the statement is true for k , then it is also true for $k + 1$. This completes our proof.

7. Prove that for all natural number n , $11^n - 6$ is divisible by 5.

Proof:

$$\begin{aligned} \text{Part 1. } n = 1 \quad & 11^1 - 6 = 11 - 6 = 5 \checkmark \\ n = 2 \quad & 11^2 - 6 = 121 - 6 = 115 \checkmark \end{aligned}$$

Part 2: IH. Suppose that k is a natural number such that $11^k - 6$ is divisible by 5. Then there exists integer α such that $11^k - 6 = 5\alpha$. Consider now $11^{k+1} - 6$

$$11^{k+1} - 6 = 11 \cdot 11^k - 6 = (10 + 1) 11^k - 6 = 10 \cdot 11^k + 11^k - 6 = 5 \left(2 \cdot 11^k \right) + 5\alpha = 5 \left(2 \cdot 11^k + \alpha \right)$$

Therefore, if $11^k - 6$ is divisible by 5, then so is $11^{k+1} - 6$. This completes our proof.

8. Prove that for all natural number n , $2^{3n} - 3^n$ is divisible by 5.

Proof: Part 1:

$$\begin{aligned} n = 1 : \quad & 2^3 - 3^1 = 8 - 3 = 5 \checkmark \\ n = 2 : \quad & 2^6 - 3^2 = 64 - 9 = 55 \checkmark \end{aligned}$$

Part 2: IH. Suppose that k is a natural number such that $2^{3k} - 3^k$ is divisible by 5. Then there exists integer α such that $2^{3k} - 3^k = 5\alpha$. Consider now $2^{3(k+1)} - 3^{k+1}$

$$\begin{aligned} 2^{3(k+1)} - 3^{k+1} &= 2^{3k+3} - 3^{k+1} = 2^{3k} \cdot 2^3 - 3^k \cdot 3 = 8 \cdot 2^{3k} - 3 \cdot 3^k = (5 + 3) \cdot 2^{3k} - 3 \cdot 3^k \\ &= 5 \cdot 2^{3k} + 3 \cdot 2^{3k} - 3 \cdot 3^k = 5 \cdot 2^{3k} + 3 \left(2^{3k} - 3^k \right) = 5 \cdot 2^{3k} + 3(5\alpha) = 5 \left(2^{3k} + 3\alpha \right) \end{aligned}$$

Therefore, if $2^{3k} - 3^k$ is divisible by 5, then so is $2^{3(k+1)} - 3^{k+1}$. This completes our proof.

9. Prove that for all natural number n , $2^{2n} + 24n - 10$ is divisible by 18.

Proof: Part 1:

$$\begin{aligned} n = 1 : \quad & 2^2 + 24 - 10 = 28 - 10 = 18 \checkmark \\ n = 2 : \quad & 2^4 + 24 \cdot 2 - 10 = 16 + 48 - 10 = 64 - 10 = 54 = 18 \cdot 3 \checkmark \end{aligned}$$

Part 2: IH. Suppose that k is a natural number such that $2^{2k} + 24k - 10$ is divisible by 18. Then there exists integer α such that $2^{2k} + 24k - 10 = 18\alpha$. Consider now $2^{2(k+1)} + 24(k+1) - 10$

$$\begin{aligned} 2^{2(k+1)} + 24(k+1) - 10 &= 2^{2k+2} + 24k + 24 - 10 = 2^{2k} \cdot 2^2 + 24k + 14 = 4 \cdot 2^{2k} + 24k + 3 \cdot 24k - 3 \cdot 24k + 14 \\ &= 4 \cdot 2^{2k} + 4 \cdot 24k - 40 + 40 - 72k + 14 = 4 \left(2^{2k} + 24k - 10 \right) - 72k + 54 \\ &= 4 \cdot 18\alpha - 18(4k - 3) = 18(4\alpha - 4k + 3) \end{aligned}$$

Therefore, if $2^{2k} + 24k - 10$ is divisible by 18, then so is $2^{2(k+1)} + 24(k+1) - 10$. This completes our proof.

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