(e) [6 points] Does the following code correctly instantiate a 4-bit adder? If so, say "Correct". If not, correct the code with minimal modification.

```
1  module adder(input a, input b, input c, output sum, output carry);
2  assign sum = a ^ b ^ c;
3  assign carry = (a&b) | (b&c) | (c&a);
4  endmodule
5
6
7  module adder_4bits(input [3:0] a, input [3:0] b, output [3:0] sum, carry);
8  wire [2:0]s;
9
10 adder u0 (a[0],b[0],1'b0,sum[0],s[0]);
11 adder u1 (a[1],s[0],b[1],sum[1],s[1]);
12 adder u2 (a[2],s[1],b[2],sum[2],s[2]);
13 adder u3 (a[3],s[2],b[3],sum[3],carry);
14 endmodule
```

Yes.
Explanation: Even though the wire s is swapped with the input b, the final computation produced by the module *adder* is still going to be correct since the *or* and *and* operations are commutative.

3 Boolean Algebra [15 points]

(a) [5 points] Find the simplest sum-of-products representation of the following Boolean equation. Show your work step-by-step.

$F = B + (A + \overline{C}).(\overline{A} + \overline{B} + \overline{C})$

Answer: $F = A + B + \overline{C}$

Explanation:

$F = B + (A.\overline{A} + A.\overline{B} + A.\overline{C} + \overline{A}.\overline{C} + \overline{B}.\overline{C} + \overline{C}.\overline{C})$
$F = B + 0 + A.\overline{B} + \overline{C}.(A + \overline{A}) + \overline{B}.\overline{C} + \overline{C}$
$F = (B + A.\overline{B}) + \overline{C}.(A + \overline{A}) + (\overline{B}.\overline{C} + \overline{C})$
$F = (B + A) + \overline{C} + \overline{C}.(\overline{B} + 1)$
$F = A + B + \overline{C}$

(b) [5 points] Convert the following Boolean equation so that it only contains NAND operations. Show your work step-by-step.

$F = \overline{(A + B.C)} + \overline{C}$

Answer: $F = \overline{\overline{\overline{\overline{(A.A)}.\overline{(B.C)}}}.C)}$

Explanation:

$F = \overline{\overline{(\overline{\overline{(A + B.C)} + \overline{C}})}}$
$F = \overline{\overline{(A + B.C).C)}}$
$F = \overline{\overline{\overline{\overline{(A + B.C)}}.C)}}$
$F = \overline{\overline{(\overline{A}.\overline{\overline{(B.C)}}).C)}}$
$F = \overline{\overline{\overline{\overline{(A.A)}}.\overline{\overline{(B.C)}}).C)}}$

(c) [5 points] Using Boolean algebra, simplify the following min-terms: $\sum(3, 5, 7, 11, 13, 15)$

Show your work step-by-step.

Answer: $F = D.(B + C)$

Explanation:

$\{3, 5, 7, 11, 13, 15\} = \{0011, 0101, 0111, 1011, 1101, 1111\}$

$F = (\overline{A}.\overline{B}.C.D) + (\overline{A}.B.\overline{C}.D) + (\overline{A}.B.C.D) + (A.\overline{B}.C.D) + (A.B.\overline{C}.D) + (A.B.C.D)$
$F = (C.D.((\overline{A}.\overline{B}) + (\overline{A}.B) + (A.\overline{B}) + (A.B))) + (B.D.((\overline{A}.\overline{C}) + (A.\overline{C})))$
$F = (C.D) + (B.\overline{C}.D)$
$F = D.(C + (B.\overline{C}))$
$F = D.(B + C)$