

# Test Plan for the Companion Cube Calculator ( $C^3$ ) Tool

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# 1 Revision History

Date	Version	Notes
	1.0	Initial draft completed

## 2 Symbols, Abbreviations and Acronyms

Symbol	Description
$C^3$	Companion Cube Calculator
GUI	Graphical User Interface
IDE	Integrated Development Environment
SRS	Software Requirements Specification
T	Test

[symbols, abbreviations or acronyms – you can reference the SRS tables if needed —SS]

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## 3 General Information

This document is a software test plan for the Companion Cube Calculator ( $C^3$ ), a mathematical tool which determines the range of a user-specified function given the domains of the function's variables. The calculations are performed using interval arithmetic.

### 3.1 Purpose

This document describes the software test plan for the  $C^3$  tool and is informed by its SRS documentation (version 1.0.2), including a description of automated testing approach, tools, and black box test cases. The purpose of documenting this information is to guide the product testing for the initial product release and to provide a basis for regression testing as further developments are made to the  $C^3$  tool.

This document is intended for readers who wish to test the initial version of the product, as well as those who want to refine and expand the tool. As changes are made to the  $C^3$  tool, these test cases will form the foundation of regression testing and will help ensure that any changes made to the product do not affect its original purpose or core functionality.

This test plan is intended to be used for version 1.0 of the  $C^3$  tool, and will only contain test information related to the product description in the product's SRS documentation (version 1.0.2). Any functionality defined beyond the scope of the SRS document are not included in this version of the test plan.

### 3.2 Scope

The  $C^3$  tool relies on interval arithmetic in the domain of real numbers ( $\mathbb{R}$ ), which means that many of its functions can be empirically tested. The tool has not yet been built, so the plan not include implementation-specific tests. Instead, this plan will outline black box tests that abstracts the tool into modules based on the requirements identified in the SRS documentation.

The purpose of this plan is to guide the modularization of the  $C^3$  tool design so that it is easy to test and maintain. It also forms the foundation of the kinds of behaviours that the tool should exhibit when it encounters malformed user inputs and unexpected values during its calculations.

### **3.3 Overview of Document**

This document presents a general description of the  $C^3$  tool to establish the context of the test plan and a list of team members responsible for executing it. This background information is followed by a high-level description of the test plan, including the automated testing approach, verification tools, and non-testing based verification methods that will be used. The general plan outline is followed by a description of the system test which is designed to determine if the requirements from the associated SRS document are satisfied. The final section describes how unit testing will be implemented when the internal workings of the  $C^3$  tool are established.

## **4 Plan**

This section describes the test plan for the  $C^3$  tool from a high-level perspective, outlining the methodologies and tools that will be used during the verification process, and the team responsible for executing the plan.

### **4.1 Software Description**

The  $C^3$  tool is a stand-alone application for calculating the mathematical range of a user-defined function given the domains of the function's component variables. Function ranges and variable domains are represented by intervals, where intervals are defined as a sequence of continuous values bounded by a minimum and maximum value. The minimum and maximum values for any given interval must be defined. To perform its calculations, the  $C^3$  tool uses interval arithmetic.

The purpose of this product is to produce accurate results when they can be found. If a result cannot be found, the tool is expected to communicate the reason back to the user. Calculations must be accurate within an error range of the host machine's floating point error. These tasks must be completed while presenting all communications to the user in standard function and interval notation.

### **4.2 Test Team**

The test team assigned to implement this plan is Geneva Smith.

### 4.3 Automated Testing Approach

The  $C^3$  tool will almost exclusively rely on automated test approaches for its verification process, with the notable exceptions of the non-functional requirements for correctness, verifiability, usability and maintainability described in the SRS document (version 1.0.2). The verification of correctness cannot be tested by a machine because it relies on mathematical proofs and the remaining non-functional requirements of verifiability, usability, and maintainability are intended for a human audience. These types of verifications are best handled by manual tests and user studies.

The functional requirements tests (Section 5.1) focus on the behaviour that is expected at each stage of the  $C^3$  tools work flow. Since these behaviours are internal to the tool with no user guidance, these behaviours can be tested automatically using a series of black box unit tests. Some of the non-functional requirements such as reliability and robustness (Section 5.2), can also be tested using automated approaches because they focus on floating-point error rates and data constraints.

Many of the unit tests are designed to be used as part of integration testing, and the system will be progressively tested starting from gathering user inputs and ending with the system's outputs. Outputs can be messages informing the user of erroneous behaviours or malformed inputs, and calculated result if a no errors are detected.

The remaining unit tests are designed to test the correctness of the tool's calculation. Some of the tests check simple, two variable equations to ensure that the individual calculation types are behaving correctly. The remaining tests will ensure that equations with multiple operators are being decomposed correctly by comparing it to expected results. Once a set of equations has been selected for this task, regression testing becomes available to check further developments to the  $C^3$  tool.

### 4.4 Verification Tools

The C# programming language has been chosen for the development of the  $C^3$  tool because of its GUI building capabilities. The supporting IDE, Visual Studio 2017 (Enterprise Edition), comes with a number of built-in test tools, including:

- **A unit test framework and management system**

This forms the bulk of the automated testing approach and will be used for unit, integration, system, and regression testing.

- **Automated GUI testing**

This version of Visual Studio allows developers to record a series of interactions with a GUI that can be played multiple times for testing. This can help save time by making traditionally manual test cases into automated ones. Depending on the complexity of the GUI, this tool might not be used.

- **Code coverage tools that can be run “live” as code is written**

The code coverage tools in Visual Studio is connected to the test management system and can help identify code that is not being run by any unit test. The IDE can be configured so that this code coverage check is run automatically while the program is being written.

## 4.5 Non-Testing Based Verification

There are no non-testing based verification approaches in this test plan due to time and team constraints.

## 5 System Test Description

The system testing of the  $C^3$  tool will focus on inspecting and conditioning user inputs and ensuring that the  $C^3$  tool is able to produce descriptive outputs for both valid and invalid inputs.

The goal of user input inspection and conditioning tests is to be sure that the  $C^3$  tool is able to identify and reject values that violate the assumptions. If the tool determines that the values do not violate the assumptions, it should be able to convert those values into the internal representations identified in the SRS document. For the purposes of this test plan, it is assumed that the user function is represented internally as a parse tree.

Even if the user inputs are validated and conditioned correctly, it is still possible for the  $C^3$  tool to encounter invalid operations in an intermediary step while calculating a result. This makes it necessary to create a series of tests to determine how the tool will react to both supported and unsupported operations.

This test plan is meant to be executed in stages. The first stage is a white-box unit test of the functionality required to get raw inputs from the user. The subsequent stages are both integration and unit tests, where the test checks that the behaviour produced by the new modules is both working as expected and can communicate with the modules above it. The final tests in this chain, which show



the calculations of the  $C^3$  tool, form the basis of regression testing and contains mathematical functions that will be incorrectly processed if the tool does not parse them correctly.

## 5.1 Tests for Functional Requirements

### 5.1.1 Getting User Inputs

This test suite is designed to determine if the R1 (Accepting  $f(V)$  and  $D(v)$ ,  $v \in V$  as direct input or read from a file) functional requirement is satisfied and its associated data constraints from R4.

The initial test cases (User Inputs (As Expected)) are the white-box unit tests that start the integration testing. The tests that follow these assume that these tests have passed.

#### User Inputs (As Expected)

1. test-directinput

Type: Functional, Automatic, Unit

Initial State: New Session

Input:  $f(V) = x + y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output: Input received from direct input

How test will be performed: Unit Test

2. test-fileinput

Type: Functional, Automatic, Unit

Initial State: New Session

Input: File containing:  $f(V) = x + y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output: Input received from file

How test will be performed: Unit Test

### **User Inputs (Bad File I/O)**

1. test-badFileInput

Type: Functional, Automatic, Unit

Initial State: New Session

Input: File that cannot be read

Output: Error – File cannot be read

How test will be performed: Unit Test

### **User Inputs (Function is a Constant Value)**

1. test-input\_functionAsConstant

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = 34$

Output: Warning – Function  $f(V)$  does not contain any variables

How test will be performed: Unit Test

### **User Inputs (Extraneous Information)**

1. test-input\_variableNotInFunction

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y, x = [2, 4], y = [3, 5], z = [6, 7]$

Output: Warning – Function  $f(V)$  does not contain name  $z$  found in variable list

How test will be performed: Unit Test

### User Inputs (Missing Values)

1. test-input\_noFunction

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $x = [2, 4], y = [3, 5]$

Output: Error – Could not find function  $f(V)$  with variables  $x, y$

How test will be performed: Unit Test

2. test-input\_noDomain

Type: Functional

Initial State: New Session

Input:  $f(X) = x + y, x = [2, 4]$

Output: Error – No domain for variable  $y$

How test will be performed: Unit Test

### User Inputs (Incomplete Values)

1. test-input\_missingFunctionValue1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x+, x = [2, 4], y = [3, 5]$

Output: Error – Function  $f(V)$  is missing an operand for  $+$

How test will be performed: Unit Test

2. test-input\_missingFunctionValue2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + *y, x = [2, 4], y = [3, 5]$

Output: Error – Function  $f(V)$  is missing an operand between + and \*

How test will be performed: Unit Test

3. test-input\_missingMinDomainValue

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y$ ,  $x = [, 4]$ ,  $y = [3, 5]$

Output: Error – Missing min domain value for  $x$

How test will be performed: Unit Test

4. test-input\_missingMaxDomainValue

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $\{f(V) = x + y, x = [2, 4], y = [3, ]\}$ ,  $\{f(V) = x + y, x = [2, 4], y = [3]\}$

Output: Error – Missing max domain value for  $y$

How test will be performed: Unit Test

**User Inputs (Non-Numerical Value in Domains)**

1. test-input\_nonNumberInDomain

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y$ ,  $x = [2, 4]$ ,  $y = [a, 5]$

Output: Error – Non-numerical value found in the domain for variable  $y$

How test will be performed: Unit Test

### 5.1.2 Conditioning User Inputs

This test suite is designed to determine if the R2 (Converting each  $D(v)$  into DD1) and R3 (Decomposing  $f(V)$  into two-operand equations following BED-MAS rules) functional requirements and the associated data constraints from R4 are satisfied.

The tests that follow these assume that the user input tests (5.1.1) have passed.

#### Addition, Subtraction, and Multiplication

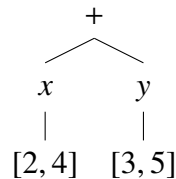
##### 1. test-parse\_addition

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output:



How test will be performed: Unit Testing

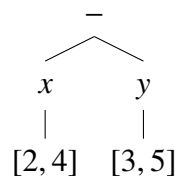
##### 2. test-parse\_subtraction

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x - y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output:



How test will be performed: Unit Testing

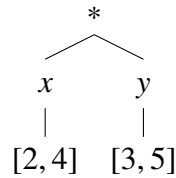
3. test-parse\_multiplication

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x * y, x = [2, 4], y = [3, 5]$

Output:



How test will be performed: Unit Testing

## Division

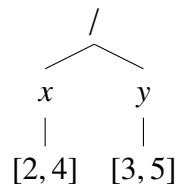
1. test-parse\_divisionPositiveDivisor

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y, x = [2, 4], y = [3, 5]$

Output:



How test will be performed: Unit Testing

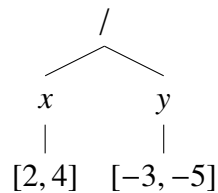
2. test-parse\_divisionNegativeDivisor

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y, x = [2, 4], y = [-3, -5]$

Output:



How test will be performed: Unit Testing

3. test-parse\_divisionMixedIntervalDivisor

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y$ ,  $x = [2, 4]$ ,  $y = [-3, 5]$

Output: Error – Cannot perform division with a mixed interval divisor

How test will be performed: Unit Testing

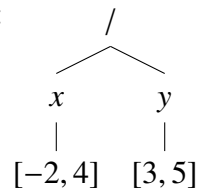
4. test-parse\_divisionMixedIntervalQuotient

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x/y$ ,  $x = [-2, 4]$ ,  $y = [3, 5]$

Output:



How test will be performed: Unit Testing

## Intervals as Exponents

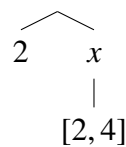
1. test-parse\_intervalAsExponents

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = 2^x$ ,  $x = [2, 4]$

Output:  $B^x$



How test will be performed: Unit Testing

2. test-parse\_intervalAsExponentsInvalidBase

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = 1^x$ ,  $x = [2, 4]$

Output: Error – Cannot perform operation with an interval exponent when the base number  $(B) \leq 1$

How test will be performed: Unit Testing

### Intervals as Base Numbers

1. test-parse\_intervalWithExponent

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^2$ ,  $x = [2, 4]$

Output:  $x^N$

$x$        $2$

$|$

$[2, 4]$

How test will be performed: Unit Testing

2. test-parse\_intervalWithInvalidExponent1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^{2.1}$ ,  $x = [2, 4]$



Output: Warning – Cannot perform operation with an exponent that is not a whole number; the exponent has been rounded to 2

$$\begin{array}{c}
 x^N \\
 \swarrow \quad \searrow \\
 x \qquad 2 \\
 | \\
 [2, 4]
 \end{array}$$

How test will be performed: Unit Testing

### 3. test-parse\_intervalWithInvalidExponent2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^{-1}$ ,  $x = [2, 4]$

Output: Error – Cannot perform operation exponentiation with an exponent ( $N$ )  $< 0$

How test will be performed: Unit Testing

## Intervals-Only Exponentiation

### 1. test-parse\_intervalsOnlyExponentiation

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x^y$ ,  $x = [2, 4]$ ,  $y = [3, 5]$

Output: Error – Cannot perform exponentiation when the base number ( $B$ ) and the exponent ( $N$ ) are intervals

How test will be performed: Unit Testing

## Precedence of Brackets

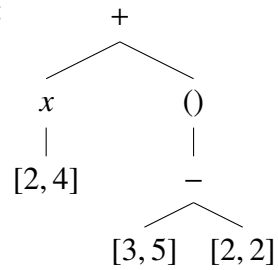
### 1. test-parse\_brackets1

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + (y - z)$ ,  $x = [2, 4]$ ,  $y = [3, 5]$ ,  $z = [2, 2]$

Output:



How test will be performed: Unit Testing

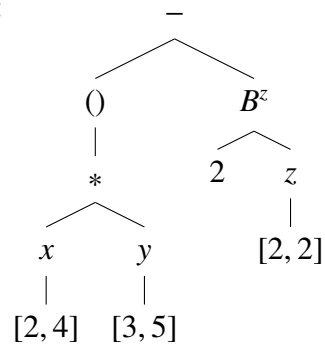
## 2. test-parse\_brackets2

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = (x * y) - 2^z$ ,  $x = [2, 4]$ ,  $y = [3, 5]$ ,  $z = [2, 2]$

Output:



How test will be performed: Unit Testing

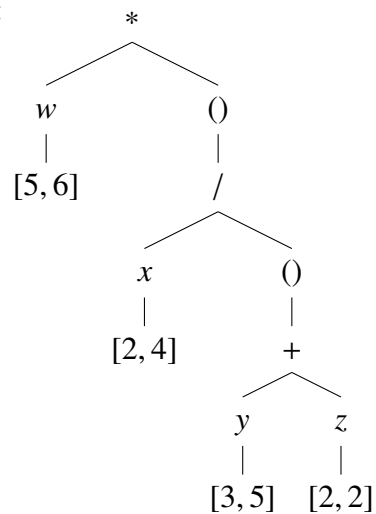
## 3. test-parse\_brackets3

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = w * (x / (y + z))$ ,  $w = [5, 6]$ ,  $x = [2, 4]$ ,  $y = [3, 5]$ ,  $z = [2, 2]$

Output:



How test will be performed: Unit Testing

### 5.1.3 Composing Operators

This test suite is designed to determine if the R5 (Solving each two-operand equation and composing the results) and R6 (Ensuring that the calculated result is represented in closed, interval form) functional requirements, and the associated data constraints from R7 are satisfied.

The tests that follow these assume that the user input tests (5.1.1) and input conditioning tests (5.1.2) have passed.

#### Correctness of Operator Composition

##### 1. test-parse\_multipleOperatorsInFX

Type: Static, Manual, Unit

Initial State: New Session

Input:  $R(f(V)) = R(f_1(V)) < op > R(f_2(V))$ , where  $R(f_1(V)), R(f_2(V))$  exist

Output: True

How test will be performed: Induction

2. test-parse\_multipleOperatorsInFX

Type: Static, Manual, Unit

Initial State: New Session

Input:  $R(f(V)) = R(f_1(V)) < op > R(f_2(V))$ , where  $R(f_1(V))$  or  $R(f_2(V))$  do not exist

Output: Error – Calculation path encountered an unsupported interval operation

How test will be performed: Induction

#### 5.1.4 Presentation of Calculations to the User

This test suite is designed to test that the final functional requirement, R8 (Showing the results to the user or an error if a result cannot be found) is satisfied. It is assumed that any inputs that do not produce a viable result have been caught previously and an appropriate error or warning message was presented to the user.

The tests that follow these assume that the user input tests (5.1.1), input conditioning tests (5.1.2), and operator composition tests (5.1.3) have passed.

#### Showing the Results to the User

1. test-parse\_outputTest

Type: Functional, Automatic, Integration

Initial State: New Session

Input:  $f(V) = x + y, x = [2, 4], y = [3, 5]$

Output:  $[5, 9]$

How test will be performed: Unit Testing

#### Regression Tests

1. test-parse\_commutativityOfAdditionSubtraction

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x + y - z == f(V) = (x + y) - z, x = [2, 4], y = [3, 5], z = [2, 2]$

Output: True

How test will be performed: Unit Testing

2. test-parse\_commutativityOfMultiplicationDivision

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x * y / z == f(V) = (x * y) / z, x = [2, 4], y = [3, 5], z = [2, 2]$

Output: True

How test will be performed: Unit Testing

3. test-parse\_precedenceOfOperators1

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x + y * z == x + (y * z), x = [2, 4], y = [3, 5], z = [2, 2]$

Output: True

How test will be performed: Unit Testing

4. test-parse\_precedenceOfOperators2

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = 2^x * y == (2^x) * y, x = [2, 4], y = [3, 5]$

Output: True

How test will be performed: Unit Testing

5. test-parse\_precedenceOfOperators3

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x^2 * y == (x^2) * y, x = [2, 4], y = [3, 5]$

Output: True

How test will be performed: Unit Testing

6. test-parse\_precedenceOfOperators4

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x * (y + z), x = [2, 4], y = [3, 5], z = [2, 2]$

Output: [10, 28]

How test will be performed: Unit Testing

7. test-parse\_simpleEquationWithDecimals

Type: Functional, Automatic, System, Regression

Initial State: New Session

Input:  $f(V) = x + y, x = [2.5, 4.33], y = [3.45, 5.555]$

Output: [6.0, 9.9]

How test will be performed: Unit Testing

## 5.2 Tests for Non-Functional Requirements

Some of the non-functional requirements can be tested using the same tests as their associated functional requirements. This includes correctness and verifiability (5.1.3), robustness (applicable at every process stage), and reliability (5.1.4). This leaves the non-functional requirements of usability and maintainability to test separately.

Due to the intended audience for the initial version of the  $C^3$  tool and the size of the test team, maintainability testing will not be covered.

### 5.2.1 Usability

#### Use of Standard Mathematical Notation

1. test-enteringFV

Type: Non-Functional, Manual, System

Initial State: New Session

Condition: The user is given a series of  $f(V)$  to enter into the tool; the  $f(V)$  chosen will be taken from the functional requirement tests (5.1)

Result: The user should be able to enter in the  $f(V)$  with no guidance

How test will be performed: Usability questionnaire (7.1.1)

2. test-enteringDv

Type: Non-Functional, Manual, System

Initial State: New Session

Condition: The user is given a series of  $D(v)$  to enter into the tool; the  $D(v)$  chosen will be taken from the same functional requirement tests (5.1) as the  $f(V)$  usability test (Test ID: test-enteringFV)

Result: The user should be able to enter in the  $D(v)$  with no guidance

How test will be performed: Usability questionnaire (7.1.1)

#### GUI Presentation and Organization

1. test-id1

Type:

Initial State:

Input/Condition:

Output/Result:

How test will be performed:

2. test-id2

Type: Functional, Dynamic, Manual, Static etc.

Initial State:

Input:

Output:

How test will be performed:

### **5.3 Traceability Between Test Cases and Requirements**

## **6 Unit Testing Plan**

[Unit testing plans for internal functions and, if appropriate, output files —SS]



## 7 Appendix

This is where you can place additional information.

### 7.1 Usability Survey Questions

#### 7.1.1 User Questions for Entering Values into the $C^3$ Tool

1. (Likert Scale) I was able to enter in the equation  $f(V)$  in a format that I was familiar with.
2. (Likert Scale) I was able to enter in the equation  $f(V)$  in a format that I was expecting.
3. (Likert Scale) I found it easy to enter the  $f(V)$  equations into the tool.
4. (Likert Scale) I was able to enter in the domains  $D(v)$  in a format that I was familiar with.
5. (Likert Scale) I was able to enter in the domains  $D(v)$  in a format that I was expecting.
6. (Likert Scale) I found it easy to enter the domains  $D(v)$  into the tool.
7. (Open Response) Do you have any suggestions for improving the mathematical notation of the  $C^3$  tool?

#### 7.1.2 User Questions for Using the $C^3$ Tool GUI

1. (Likert Scale) I found it easy to find the input mechanism for entering  $f(V)$  into the GUI.
2. (Likert Scale) I found it easy to enter the  $f(V)$  equations into the GUI.
3. (Likert Scale) I found it easy to find the input mechanism for entering  $D(v)$  into the GUI.
4. (Likert Scale) I found it easy to enter the domains  $D(v)$  into the GUI.
5. (Likert Scale) I found it easy to find the program's result for  $R(f(V))$  in the GUI.

6. (Likert Scale) I found it easy to understand the program's result for  $R(f(V))$  in the GUI.
7. (Likert Scale) I found it easy to understand the sequence of steps required to use the  $C^3$  tool.
8. (Open Response) Do you have any suggestions for improving the process flow of the  $C^3$  tool?