# AN ANALYSIS OF COMPLEXITY METRICS IN COMPUTER-AIDED DESIGN AT TEXAS A&M

An Undergraduate Research Scholars Thesis

by

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Major: Industrial and Systems Engineering

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# ABSTRACT

An Analysis of Complexity Metrics in Computer-Aided Design at Texas A&M. (May 2014)

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Computer-Aided Design (CAD) is a critical tool in the development of modern products. Companies pride themselves on their employees' CAD knowledge with respect to the products they are able to model. It is important that educators make an effort to understand what students find difficult with regards to modeling, in order to help better teach CAD. Currently, there are a few complexity metrics found in literature such as the part volume ratio, sphere ratio or area ratio. This work will investigate the three ratios above as they apply to a complexity survey of 10 shapes given to students. This work will focus on finding which complexity metric most similarly correlates to the responses of students at Texas A&M University.

# DEDICATION

I dedicate this work to my family, friends, and mentors. Without their continued encouragement and words of wisdom this would not have been possible.

# ACKNOWLEDGEMENTS

I would like to thank Dr. Michael Johnson for his outstanding encouragement, support, and advice.

# NOMENCLATURE

| | |
|---|---|
| CAD | Computer-Aided Design |
| 2D | Two Dimensional |
| 3D | Three Dimensional |
| IRB | Institutional Review Board |

# CHAPTER I

# INTRODUCTION

Computer-Aided Design plays a huge role in the creation and manufacturing of products. To help a product through its development process, CAD can model anything from sports cars to sports equipment. CAD can save a company thousands if not millions of dollars by running a product through computer simulations for tests before having to manufacture the product. CAD software is a means for people to see something that is still a concept before it's built. CAD knowledge plays an essential role in the designer's ability to create a product on the computer. Lack of CAD knowledge could also mean taking 3 times as long to model the same item as your colleague.

Companies spend efforts training new employees to teach them all the tools of the CAD modeling process. A possible application of this work is in the classroom. Having a metric with which to gauge complexity will aid teachers in deciding if an object is too complex to teach at that moment. Another possible application of this work involves 3D printing. With an increasing number of users interested in 3d printing, it's important to establish a measure for 3D cad model complexity. This measure will help define an appropriate cost for 3d printing. Currently multiple techniques exist to outline shape similarities however there is no algorithm to designate shape complexity a shape individually. This work will focus on surveying CAD users at Texas A&M University to find what they believe to be geometric complexity with respect to CAD, followed by quantifying the survey's results.

# CHAPTER II

# METHODOLOGY

## Geometric Complexity Survey

First, Institutional Review Board (IRB) approval was attained from Texas A&M. This type of approval must always be obtained when testing on human subjects is involved; this is done in order to protect the test subjects from any harm. The committee behind approval weighs potential risks and benefits in order to decide approval.  After obtaining IRB approval, students from ENDG 105, ENDG 407 and ENTC 422 were recruited to participate in the survey. In total 168 participants completed the consent form and survey. The survey that was given to participants can be seen in Appendix A. This survey gauged participants CAD related coursework, thoughts on geometric complexity, and also asked their opinion of the geometric complexity associated with 10 shapes which can be seen below in Figure 2. The geometric complexity of the 10 shapes was rated on a scale of 1 to 5, with 1 being very simple and 5 being very complex. Results of the students' survey data can be seen in Appendix B-Appendix D.


**Figure 1: Breakdown of 3 Participant Groups**

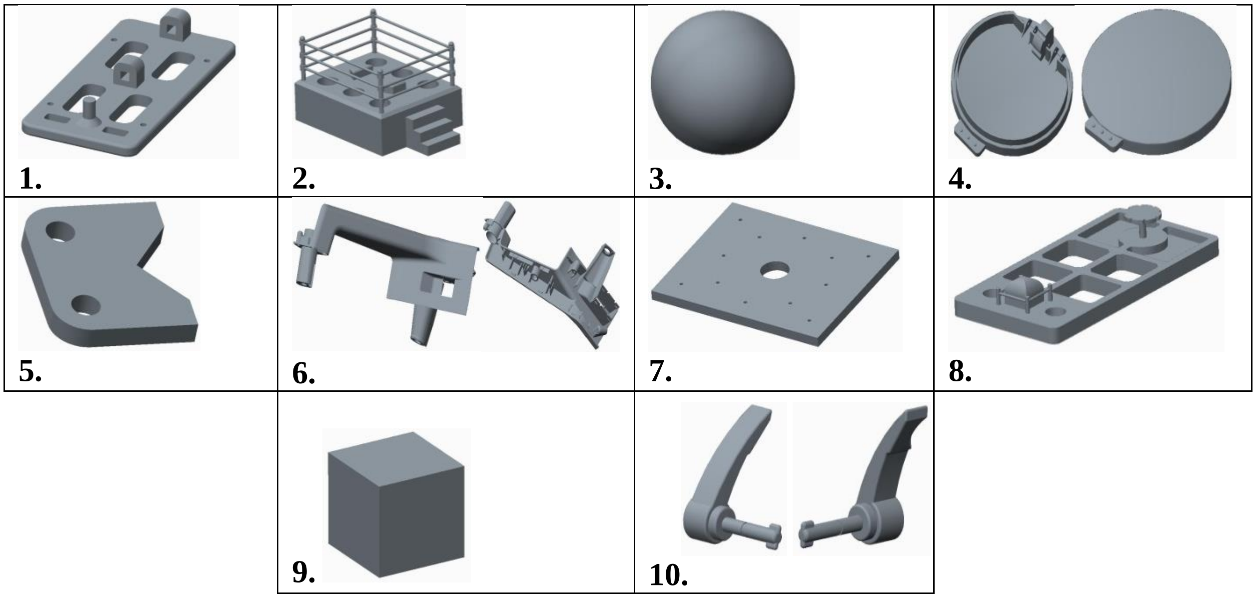


**Figure 2: Graphical View of All Shapes**

## Shape Complexity Measures

After reading several pieces of literature, there were 3 complexity metrics that were deemed broadly applicable, Part Volume ratio, Sphere Ratio, Area Ratio. The same 10 CAD parts students are surveyed on, are rated with a complexity metric. These complexity metrics were calculated for the same 10 components for which student survey data was obtained.

### *Part Volume Ratio*

The ratio between the volumes of the part ($V_b$) to the volume of a box that bounds that part ($V_b$) is known as the Part Volume Ratio [1]. To find the volume of the bounding box, use the largest length, width and height of the part. The equation for this can be seen below.

$$\boldsymbol{Part\ Volume\ Ratio = 1 - \frac{V_p}{V_b}} \qquad \text{(Equation1)}$$

*Sphere Ratio*

The ratio between the surface area of an equivalent sphere to the surface area of the part is known as the Sphere Ratio [1]. The equation for this can be seen below.

$$\text{Surface area of an equivalent sphere} = \ A_s = (4 \times \pi)^{1/3}(3 \times V_p)^{2/3} \quad \text{(Equation2)}$$

$$\text{Sphere Ratio} = 1 - \frac{A_s}{A_p} \quad \text{(Equation3)}$$

*The Area Ratio*

A ratio between the surface areas of: a cube of equal volume to that of the original part divided by the surface area of the solid part is known as The Area Ratio [2]. This equation can be seen below.

$$\text{Area Ratio} = 100\ \times \left(1 - \left(\frac{\text{Surface area of cube of equal volume}}{\text{surface area of solid}}\right)\right) \quad \text{(Equation4)}$$

In order to calculate the surface area of a cube of equal volume you must first find the length of one of the edges. By taking the cubed root of the volume of the part you can find the length of an edge. By using the formula for surface area of a cube, you can find the surface area of a cube of equal volume to that of a part.

$$\text{Surface Area of Cube of Equal Volume} = 6 \times (\text{length of side})^2 \quad \text{(Equation5)}$$

**Normality Test**

Students' survey results were statistically analyzed using Minitab software. Initially, basic statistics were run on all 10 CAD drawings. These basic statistics can be seen in Appendix E Figures 1 -10, a summary of the results can be seen in the results section Table1: Basic Statistical Summary Results. As a part of the basic statistics done on the responses for each of the 10 shapes, the Anderson Darling (AD) Normality Test was completed. What is important to note here is that if the p-value given as a result of the AD test is greater than or equal to 0.05 then the data provides statistical evidence that it follows a normal distribution. Data following a normal distribution determines the course of statistical testing to follow. In the case of our data none of the data followed a normal distribution, so we must test our data using a t-test.

**T-Test**

The t-test is a statistical test that compares two means in order to determine if the means are equal. The purpose of running this test is so that it can be determine if the students in both of the groups involved in the t-test agreed on the geometric complexity to the CAD part in question. The T-Test was run by class for each part. The students' responses from each question of the ENTC 422 students were tested against the responses of the respective question answered by ENDG 407; and ENTC 422 students' responses for each question were also tested against those responses made by ENDG 105 students. The results of this test can be seen in the results section Table2: Two Sample T-Test Results.

**Spearman's Rho**

Finally, students' responses were tested in Minitab using the Spearman's Rho correlation against the complexity metrics outlined earlier. Spearman's rho, also known as Spearman's rank correlation coefficient, is a statistical analysis method that measures the relationship between two sets of data by measuring the two different ranks. Minitab results of this can be seen in Appendix H: Spearman's Rho Statistical Analysis Results, and a summary of the results can be found in the results section Table 3: Spearman's Rho Correlation Results. It is important to note that according to Minitab, p-values should not be used to interpret spearman's rho calculations.

Results of the spearman's rho calculation should be between -1 and +1, where, if the result is negative one variable increases as the other increases. Similarly, if the result is positive, both variables increase or decrease together.

# CHAPTER III

# RESULTS

### Basic Statistical Summary Results

As mentioned previously, basic statistics were measured of each question. Below is a table summarizing the results. It is important to note that participants thought the shape associated with question 9 to be the least complex shape of the group, and the shape associated with question 6 to be the most complex of the group. Pictographic representations of all basic statistics can be seen in Appendix E.

**Table 1: Basic Statistical Summary Results**

| Figure Number | Basic Statistics | Figure Number | Basic Statistics | | |
|---|---|---|---|---|---|
| Figure 1 | N = 168<br>Mean = 2.91<br>Standard deviation = 0.95<br>Anderson-Darling Normality Test P-Value = <0.005 | Figure 4 | N = 168<br>Mean = 3.79<br>Standard deviation = 0.83<br>Anderson-Darling Normality Test P-Value = <0.005 | Figure 7 | N = 168<br>Mean = 1.83<br>Standard deviation = 0.72<br>Anderson-Darling Normality Test P-Value = <0.005 |
| Figure 2 | N = 168<br>Mean = 3.44<br>Standard deviation = 0.92<br>Anderson-Darling Normality Test P-Value = <0.005 | Figure 5 | N = 166<br>Mean = 1.59<br>Standard deviation = 0.64<br>Anderson-Darling Normality Test P-Value = <0.005 | Figure 8 | N = 168<br>Mean = 3.64<br>Standard deviation = 0.86<br>Anderson-Darling Normality Test P-Value = <0.005 |
| Figure 3 | N = 167<br>Mean = 1.37<br>Standard deviation = 0.95<br>Anderson-Darling Normality Test P-Value = <0.005 | Figure 6 | N = 168<br>Mean = 4.79<br>Standard deviation 0.43<br>Anderson-Darling Normality Test P-Value = <0.005 | Figure 9 | N = 168<br>Mean 1.12<br>Standard deviation 0.35<br>Anderson-Darling Normality Test P-Value = <0.005 |
| | | | | Figure 10 | N = 168<br>Mean = 3.72<br>Standard deviation = 0.78<br>Anderson-Darling Normality Test P-Value = <0.005 |

## Two Sample T-Test Results

Results from the two sample T-Test are as shown in the table below. For a complete list of results see Appendix G

### Table 2: Two Sample T-Test Results

| Groups Being Tested | P-Value | Groups Being Tested | P-Value |
|---|---|---|---|
| ENTC 422 Q1, ENDG 407 Q1 | 0.739 | ENTC 422 Q1, ENDG 105 Q1 | 0.000 |
| ENTC 422 Q2, ENDG 407 Q2 | 0.120 | ENTC 422 Q2, ENDG 105 Q2 | 0.200 |
| ENTC 422 Q3,ENDG 407 Q3 | 0.359 | ENTC 422 Q3, ENDG 105 Q3 | 0.005 |
| ENTC 422 Q4, ENDG 407 Q4 | 0.526 | ENTC 422 Q4, ENDG 105 Q4 | 0.132 |
| ENTC 422 Q5, ENDG 407 Q5 | 0.025 | ENTC 422 Q5, ENDG 105 Q5 | 0.000 |
| ENTC 422 Q6, ENDG 407 Q6 | 0.960 | ENTC 422 Q6, ENDG 105 Q6 | 0.013 |
| ENTC 422 Q7, ENDG 407 Q7 | 0.224 | ENTC 422 Q7, ENDG 105 Q7 | 0.000 |
| ENTC 422 Q8, ENDG 407 Q8 | 0.122 | ENTC 422 Q8, ENDG 105 Q8 | 0.000 |
| ENTC 422 Q9, ENDG 407 Q9 | 0.268 | ENTC 422 Q9, ENDG 105 Q9 | 0.001 |
| ENTC 422 Q10, ENDG 407 Q10 | 0.819 | ENTC 422 Q10, ENDG 105 Q10 | 0.058 |

## Spearman's Rho Results

Below are the results based on the Separman's Rho correlation. The direct Minitab results of this correlation can be seen in Appendix H.

### Table 3: Spearman's Rho Correlation Results

| Groups being Correlated | Ratio | Groups being Correlated | Ratio |
|---|---|---|---|
| All Students and Part Volume Ratio | 0.927 | ENDG 105 and Sphere Ratio | -0.818 |
| All Students and Area Ration | -0.770 | ENDG 407 and Sphere Ratio | -0.736 |
| All Students and Sphere Ratio | -0.770 | ENTC 422 and Sphere Ratio | -0.733 |
| ENDG 105 and Part Volume Ratio | 0.891 | ENDG 407 along with ENTC 422 and Sphere Ratio | 0.273 |
| ENDG 407 and Part Volume Ratio | 0.936 | ENDG 105 and ENTC 422 | 0.927 |
| ENTC 422 and Part Volume Ratio | 0.903 | ENDG 407 and ENTC 422 | 0.985 |
| ENDG 407 along with ENTC 422 and Part Volume Ratio | -0.830 | ENDG 407 along with ENTC 422 and ENDG 105 | -0.697 |
| ENDG 105 and Area Ratio | -0.818 | ENTC 422 and Area Ratio | -0.733 |
| ENDG 407 and Area Ratio | -0.736 | ENDG 407 along with ENTC 422 and Area Ratio | 0.273 |

# CHAPTER IV

# DISCUSSION

When testing the ENTC 422 class alongside the ENDG 407 class there was only one occurrence where the p-value was not greater than α of 0.05. Thus, for all of shapes with the exception of the shape in question 5, students from ENTC 422 and ENDG 407 found the shape complexity to be the same. According to the t-test, when referring to the 422 and 105 group, in measuring only 2 out of 10 shapes were found to have the same geometric complexity across the two groups.

Correlations were found in several of the user groups tested. In general it can be said that a strong correlation exists when the correlation ratio between them is greater than 0.8 or less than -0.8. Strong correlations were found after testing several of the combinations outlined above. Most interestingly, part volume ration was the only one of the 3 complexity metrics that had a strong correlation to the overall average students' complexity rating.

Area and Sphere ratios only held a strong correlation when comparing them to students of the ENDG 105 class. Lastly, when placing ENDG 105 students' average ranking versus that of the ENTC 422 students', it was found that a strong correlation exists. Additionally, an even stronger correlation is found in comparing the geometric complexity ranking assigned by students from ENDG 407 to that of those in ENTC 422.

# CHAPTER V

# CONCLUSION

Participants from 3 different courses were encouraged to take the survey seen in Appendix A The purpose of this survey is to help the author learn what parts CAD users believe to be geometrically complex. In addition, this survey asked what in particular CAD users found difficult to model with respect to CAD. It was found that the complexity measure also known as Part Volume Ratio most closely correlates with Texas A&M students' responses. Part Volume Ratio is the ratio of the volume of the part in question, and the volume of the smallest bounding box of that part. This positive correlation can be of great use to CAD instructors and even 3D printing companies. CAD instructors can use this to judge the complexity of a part assigned for homework or on a test in order to make sure students are not overloaded. Printing companies can use this measure to assess not only printing volume, but also geometric complexity. If a part is more geometrically complex, it is clear that it should cost more to print it. Finally this work is of significance because it could potentially lead to a correlation between model complexity and time to model an object.

**Forward Work**

As forward work to this thesis, data should be collected from industry professional. Additionally, work should be done to find a correlation between model complexity and some of the other metrics associated with this work such as adaptive expertise, and time to model an object.

# REFERENCES

[1] J. Durgesh, R. Bhallamudi, 1st Initial. , " Quantifying the Shape Complexity of Cast Parts," *Computer-Aided Design and Applications*, Vol. , no. , 685-700, 2010.

[2] R. Chougule, B. Ravi, 1st Initial. , "Variant process planning of castings using AHP-based nearest neighbor algorithm for case retrieval," *International Journal of Production Research*, Vol. 43, no. 6, 1255-1273, 2005.

## APPENDIX A: Participant Survey

Please check the computer-aided design (CAD) or computer-aided manufacturing (CAM) courses you have taken. If you are currently enrolled in any of the following courses, please put a "C" next to that course.

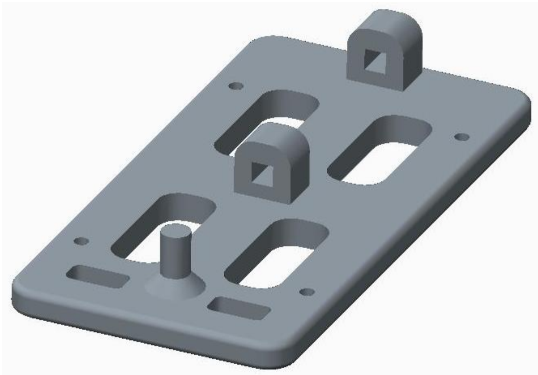
___ENDG 105 ___ENDG 407 ___ENDG 408

___ENTC 361 ___ENTC 380 ___Other (please describe):____________________

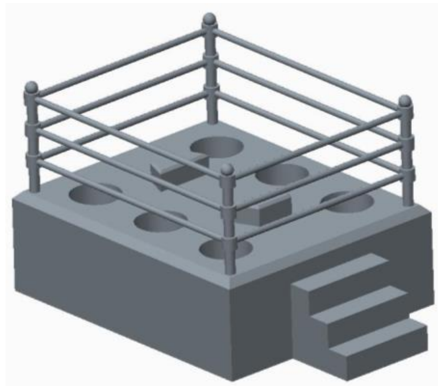
Define what you think geometric complexity means with respect to CAD:

What shapes do you think are difficult to draft with respect to CAD?

Please look at all 10 items shown below; then circle the term that best describes the geometric complexity for each of the objects.

1. 

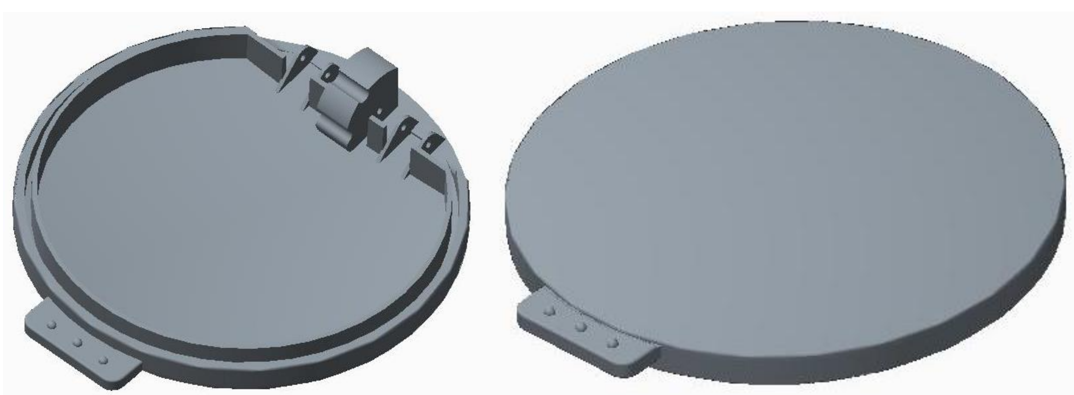
| Very Simple | Simple | Moderate | Complex | Very Complex |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

1. 

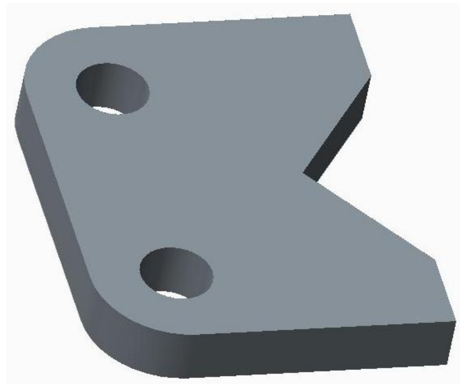
| Very Simple | Simple | Moderate | Complex | Very Complex |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

2. 

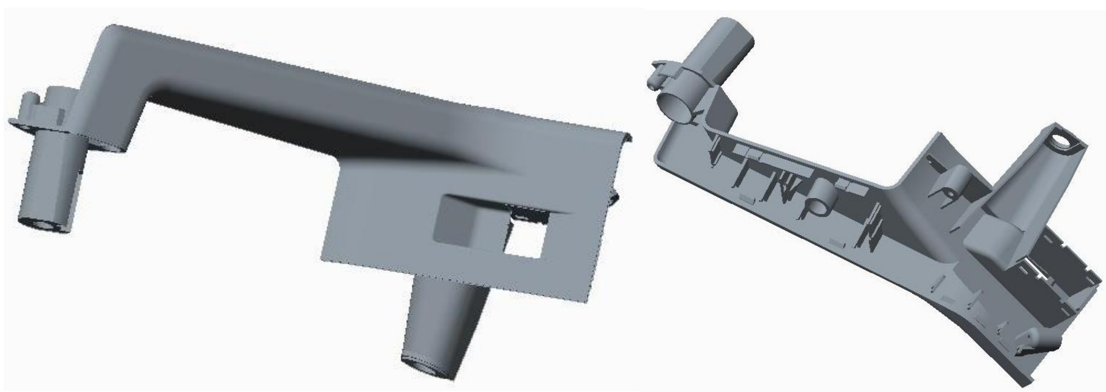
| Very Simple | Simple | Moderate | Complex | Very Complex |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

3. 

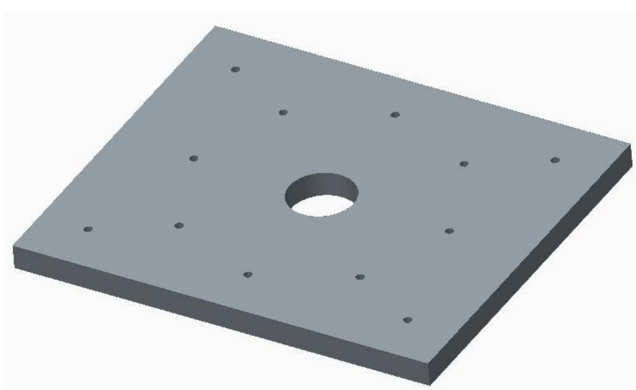
| Very Simple | Simple | Moderate | Complex | Very Complex |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

4. 

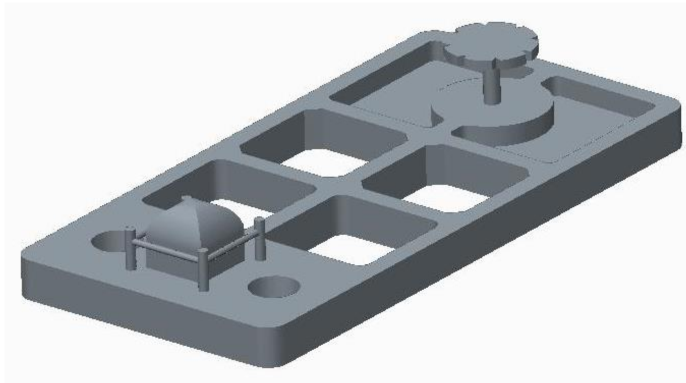
| Very Simple | Simple | Moderate | Complex | Very Complex |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

5. 

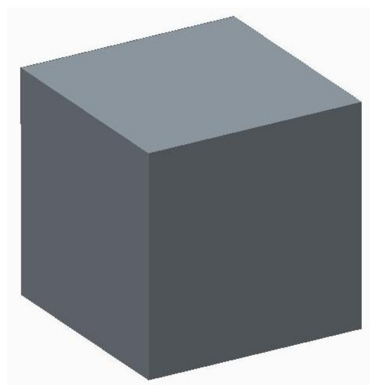
| Very Simple | Simple | Moderate | Complex | Very Complex |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

6. 

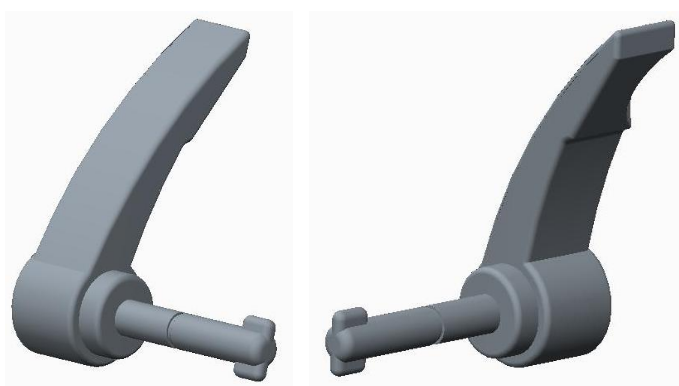
| Very Simple | Simple | Moderate | Complex | Very Complex |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

7. 

| Very Simple | Simple | Moderate | Complex | Very Complex |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

8. 

| Very Simple | Simple | Moderate | Complex | Very Complex |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

9. 

| Very Simple | Simple | Moderate | Complex | Very Complex |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

# APPENDIX B: Participant Demographic Information

## Table B-1: Participant Demographic Information

| Student No. | ENDG 105 | ENDG 407 | ENDG 408 | ENTC 361 | ENTC 380 | Other |
|---|---|---|---|---|---|---|
| 1 | Yes | | | Yes | Yes | |
| 2 | | | | Yes | Yes | ENGR 112 |
| 3 | | Yes | | Yes | Yes | |
| 4 | Yes | | | Yes | Yes | |
| 5 | | | | Yes | Yes | |
| 6 | | | | Yes | Yes | |
| 7 | | | | Yes | Yes | Community College |
| 8 | | Yes | | Yes | Yes | |
| 9 | | Yes | | Yes | Yes | |
| 10 | | | Yes | Yes | Yes | ENGR 111 |
| 11 | | Yes | | Yes | | |
| 12 | | | | Yes | Yes | ENGR 112 |
| 13 | Yes | | | Yes | Yes | |
| 14 | Yes | Yes | | Yes | Yes | |
| 15 | Yes | Yes | | Yes | Yes | |
| 16 | | Yes | | Yes | Yes | |
| 17 | | | | Yes | Yes | |
| 18 | | | | Yes | Yes | ENGR 111, ENGR 112 |
| 19 | | C | | Yes | Yes | |
| 20 | | C | | Yes | Yes | |
| 21 | | C | | Yes | Yes | |
| 22 | | | | Yes | Yes | |
| 23 | | Yes | | Yes | Yes | |
| 24 | | Yes | | Yes | Yes | |
| 25 | | | | Yes | Yes | |
| 26 | | | | Yes | Yes | |
| 27 | | | | Yes | Yes | |
| 28 | | | | Yes | Yes | |
| 29 | | | | Yes | Yes | ENGR 111, ENGR 112 |
| 30 | | C | | Yes | Yes | |
| 31 | Yes | | | Yes | Yes | |
| 32 | | | | Yes | Yes | MEEN |
| 33 | | | | Yes | Yes | ENGR 111, ENGR 112 |
| 34 | | Yes | | Yes | Yes | |
| 35 | | Yes | | Yes | Yes | |
| 36 | | Yes | | Yes | Yes | |
| 37 | Yes | Yes | | Yes | Yes | |
| 38 | Yes | Yes | | Yes | Yes | |
| 39 | Yes | Yes | | Yes | Yes | |
| 40 | Yes | C | | Yes | Yes | |
| 41 | | | | Yes | Yes | Community College CAD |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | course |
| 42 | | C | | Yes | Yes | |
| 43 | C | | | | | |
| 44 | C | | | | | |
| 45 | C | | | | | ENGR 112 |
| 46 | C | | | | | |
| 47 | C | | | | | |
| 48 | C | | | | | |
| 49 | C | | | | | |
| 50 | C | | | | | |
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| 68 | C | | | | | |
| 69 | C | | | | | |
| 70 | C | | | | | |
| 71 | C | | | | | |
| 72 | C | | | | | |
| 73 | C | | | | | |
| 74 | C | | | | | |
| 75 | C | | | | | |
| 76 | Yes | C | | | | |
| 77 | | Yes | | | | |
| 78 | Yes | C | | Yes | Yes | |
| 79 | | C | | | | |
| 80 | Yes | Yes | | | | |
| 81 | | C | | | | ENGR 111/112 |
| 82 | | C | | | | |
| 83 | | C | | | | |
| 84 | | C | | | | ENGR 111/112 |
| 85 | | C | | | | |
| 86 | N/A | N/A | N/A | N/A | N/A | N/A |
| 87 | Yes | Yes | | | | |
| 88 | Yes | C | | | | |
| 89 | | C | | | | NTNU Norway |
| 90 | Yes | C | | | | |
| 91 | | Yes | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 92 | | Yes | | | | |
| 93 | | C | | | | ENGR 111/112 MEEN 442 |
| 94 | | Yes | | | | |
| 95 | | C | | | | |
| 96 | | C | | | | |
| 97 | | Yes | | | | |
| 98 | Yes | C | | | | |
| 99 | | Yes | | | | |
| 100 | | C | | | | |
| 101 | Yes | Yes | | | | |
| 102 | | C | | | | |
| 103 | N/A | N/A | N/A | N/A | N/A | N/A |
| 104 | N/A | N/A | N/A | N/A | N/A | N/A |
| 105 | | C | | Yes | Yes | ENDG 111, ENDG 112 |
| 106 | | C | | | | |
| 107 | | C | | | | |
| 108 | | C | Yes | | | |
| 109 | Yes | C | | | | |
| 110 | | C | | | | |
| 111 | | C | | C | Yes | |
| 112 | Yes | C | | | | |
| 113 | | C | | Yes | Yes | |
| 114 | | C | | | | ENGR 111, ENGR 112 |
| 115 | | C | | | | |
| 116 | | C | | Yes | Yes | ENGR 111, ENGR 112 |
| 117 | | C | | | | |
| 118 | | C | | Yes | Yes | |
| 119 | | C | | | | |
| 120 | | C | | | | ENGR 111, ENGR 112 |
| 121 | | C | | | | |
| 122 | Yes | C | | | | |
| 123 | | C | | | | |
| 124 | | C | | | | |
| 125 | Yes | C | | Yes | Yes | |
| 126 | | C | | | | |
| 127 | | C | | | | |
| 128 | | C | | | | |
| 129 | | C | | | | |
| 130 | Yes | C | | | | |
| 131 | | C | | | | |
| 132 | | Yes | | | | |
| 133 | | C | | | | |
| 134 | Yes | C | | Yes | Yes | |
| 135 | Yes | C | | | | |
| 136 | C | | | | | |
| 137 | C | | | | | |
| 138 | C | | | | | |
| 139 | C | | | | | |

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|---|---|---|---|---|---|---|
| 140 | C | | | | | |
| 141 | C | | | | | |
| 142 | C | | | | | |
| 143 | C | | | | | |
| 144 | C | | | | | |
| 145 | C | | | | | |
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| 168 | C | | | | | |
| 169 | C | | | | | |
| 170 | C | | | | | |
| 171 | C | | | | | |
| 172 | C | | | | | |

# APPENDIX C: Study Participant Thoughts on Complexity

| Student No. | Define what you think geometric complexity means with respect to CAD | What shapes do you think are difficult to model with respect to CAD |
|---|---|---|
| 1 | the relative quantity of geometric features a part or object possess. The specific geometries are also a factor | shapes with very large numbers of irregular features are time-consuming to model |
| 2 | shapes with changing cross sectional form and size | fillets, ellipses |
| 3 | the difficulty in making a certain geometry | abstract shapes or shapes with various different details |
| 4 | the amount of irregularity of a shape | helix, a sensitivity, shapes with many extrusions |
| 5 | a part with complex shapes, or many simple shapes with intricate motions | gear splines and tooth because of the replicating nature and tolerance required |
| 6 | how difficult or time consuming it is to model | shapes that take multiple steps to make |
| 7 | The degree of which one uses differing shapes and features to create a part | Mostly Lofts |
| 8 | Geometric Complexity is how different or how mayn different steps it will take o 3d model a figure | Very intricate or precise shape that use the relative or sweep/loft commands |
| 9 | How many Steps it might take to create a certain eature in CAS | Curved shapes |
| 10 | Geometric Complexity mean the difficulty associated with representing a shape/model in CAD | Sponges, organic shapes |
| 11 | The varying degrees of complication of a 3d parts feature | sherically shaped features that are joined to non spherically shaped parts at multiple locations. Shapes that trquire precise ___ into other shapes with varying tolerances |
| 12 | The number of individual features on a part | Shapes containing irregular curves, or freehand organic splines |
| 13 | Goemetric complixity mean parts that are difficult to model due to their geometry | shapes that are combined with one another |
| 14 | How difficult it is to 3D model a feature | Lofts |
| 15 | The amount and variety of features of a part. Parts with more extrusions, contours and fillets etc tend to be more geometrically complex | Shapes are easy contours tend to be difficult, the hardest shapes tend to be non-uniform ones such as a rhombus or polygon with non uniform sides |
| 16 | The amount of features on a part and how they are arranged | any angled extrusion |
| 17 | How hard it is to make a part | shapes on a curved surface |
| 18 | how complex the geometries of an object are | hollow shapes |
| 19 | The amount of differeent dimensions a drawing has and the amount of different planes | Blank |

| | | |
|---|---|---|
| 20 | A combination of shapes that require many different commands to create | irregular shapes that arent symmetrical and don't follow any pattern |
| 21 | number of steps/features to create | Blank |
| 22 | Difficulty to model given dimensions | Blank |
| 23 | Part geometry that can not be related or derived from other part geometry | irregular and conical shapes |
| 24 | Complex shapes and curves that would add difficulty to manufacturing designed peces | curved lines that create a specific, curved surface(i.e. streamline car hoods, fenders, etc) |
| 25 | A number of different shapes arranged in a irrregular way so as to not be symmetrical | flanges and other protutions |
| 26 | geometric complexity with respect to CAD is the number of features present in the rendering | shapes that are not constant i.e. not spheres cubes and linear models |
| 27 | The higher the number of surfaces and more complex angles would make the geometry complex | rotations around a curved axis |
| 28 | creating objects of unsual geometric form for example creating a curved hollow vase as opposed to a solid cylinder | usually something with wave features |
| 29 | Geometric complexity means how difficult it is to a change a design in CAD | ones with varying curves |
| 30 | The amount of time required to generate an object i.e. no patterns | perfect springs |
| 31 | the amount of different surfaces on a part | non-symetrical parts |
| 32 | The shape of an object | three axis non planner extrusions |
| 33 | The amount of features that might be difficult to model | Curved surfaces (he drew an example) |
| 34 | The amount of time and skill taken to model a part or system | Asymetrical parts, flat and uneven parts |
| 35 | The detail in the geomteric object | curved patterns |
| 36 | design limits and constraint definition | isometric |
| 37 | the difficulty of how to draw an object | star |
| 38 | the amount of individual features and constraints within a given design | complex shapes |
| 39 | how many features curves and other aspects make up a part define its complexity | complex curves with varying radii |
| 40 | How detailed in regards to plains and axis a model can get | extruded curved features and inclines |
| 41 | The amount of features that an object has making the cad rendering more time consuming to create | any od shapes with non standard curves i.e. curves deffined long extrusions. |
| 42 | The amount of features a part has. The more complex the part the longer it will take to model for example having fillet ads complexity. | Any nontraditional shape. If it isnt a square or a circle it can be more time consuming. |
| 43 | How much effort it takes to model a part relative to its size. Small parts requiring greater effort are geometrically complex. | Anything there isn't a tool for |

| | | |
|---|---|---|
| 44 | It is the difficulty that geometric object is to build in CAD | Spheres |
| 45 | How difficult an object is to mentally visualize, model, and dimension in a CAD program | Non-symmetrical shapes. Shapes with complex system of levels |
| 46 | How difficult a shape or part is to create effectively | small and irregularly shapped objects |
| 47 | Shapes that are difficult to model in CAD software | Curved Objects |
| 48 | The difficulty assigned to different combinations of shapes and objects time and precision required | shapes with a variety of intricate pieces or parts. 3-D non linear objects |
| 49 | The object you are creating on CAD has complex shapes, angles, dimensions, etc to it | very irregular shapes with a lot of curves |
| 50 | objects with many small sometimes meshed together objects | noncommon irregular shapes like object 6 and hinge on 4 |
| 51 | The number of features and attributes of a CAD object | rounds projected along a path |
| 52 | Geometric complexity is how many features a certain object has | shapes with many unique features |
| 53 | The more complex it is the more features the object has to construct | blank |
| 54 | how in depth the shapes are in ways of editing, sizing, and geometric movement | 3-D objects |
| 55 | The amount of time/effort that it would take to accurately depict the object | shapes with a lot of intricacy or many smal unique parts |
| 56 | The software has geometric information stored to use as guidelines when drawing shapes that makes it easier on the user | ovals |
| 57 | multiple details and additions in a basic object | irregular objects |
| 58 | a lot of lines | aris |
| 59 | geometric complexity with respect to CAD mean an object that takes time, knowledge of CAD and advanced skills to make | objects with lots of detail |
| 60 | blank | depends |
| 61 | how difficult something (a object) is to draw in AutoCAD | rounded surface |
| 62 | how detailed an object is and its difficulty to create | combinations of shapes i.e. 1/2 circle 1/2 polygon etc |
| 63 | how hard something is to design | Blank |
| 64 | how difficult the shapes are to model in CAD | pretty much all of them |
| 65 | quality of differing shapes involved in the drawing of a certain object | ellipses, irregular shapes |
| 66 | if the geometry of the object is acurate to the difficult designs that CAD can do | shapes with a lot of depth |
| 67 | complex shapes and objects that are difficult to create | abstract objects that aren't common |
| 68 | how complex and detailed an object in CAD can be | tetrahedrals |
| 69 | blank | blank |
| 70 | how difficult it is to make a shape using the CAD program | I can't say I have any actual experience making difficult shapes |

| | | |
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| 71 | how hard it is to draw | shapes that aren't on the pallete |
| 72 | the complexity of shapes and designs to be done in CAD | blank |
| 73 | How hard it is that model the object in CAD | shapes that extruded from the object and are round |
| 74 | don't really know | very detailed obj. |
| 75 | complex shapes | have not encountered any |
| 76 | The level of difficulty with which CAD programs can seamlessly manipulate shapes whether constrained or otherwise. | High polygon count or rigorously constrained solids or geometries. |
| 77 | How in depth the design of a structure is relative to one's capabilities. | Complex multi-segmented structures. |
| 78 | Various orientations with little symmetry. | Shapes that are not symmetric, rely little on existing functions or require tight tolerance. |
| 79 | In terms of CAD, geometric complexity means that the more involved the design, the more complex it is. | Ones that cannot be created by simple objects, such as rectangles, spheres, etc. |
| 80 | The difficulty level in regards to creating a shape in auto CAD. | Ovals |
| 81 | I believe geometric complexity involves the level of difficulty to recreate or model a design from real life. It also involves the amount of geometric constraints that have to be followed in order to model the design. | Possible engine parts and anything related to manufacturing. |
| 82 | The difficulty associated with creating different geometric shapes in CAD. | Sweeping shapes as well as irregular, non-orthogonal shapes. |
| 83 | The algorithm needed to create/build various geometric drawings. | Multiple shapes linked together, especially those besides the standard/basic known shapes. |
| 84 | The complexity of an object in all 3 dimensions. | Things such as engine blocks. |
| 85 | The more geometric complexity the more time it will consume to actually reproduce that part. | Shells, the computer really slows down after you do a shell command and add to it. |
| 86 | N/A | N/A |
| 87 | The level of detail regarding a specific shape which one is working with CAD | 3D figures with a lot of minor details. |
| 88 | The complexity of the model or drawing in respect to the shapes or geometry of the object. | N/A |
| 89 | Objects that are difficult to produce//create in a software | rounded shapes/arcs |
| 90 | The amount of geometric detail of a prat been designed. | Round shapes. |
| 91 | The degree of difficulty or complexity of a computer generated model has. | Not sure. |

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| 92 | Something that takes time and effort to model. | Unusual shapes (not circle, square, rectangle) or a variety of shapes; a shape that would take time to create. |
| 93 | How many different shapes and complex shapes make up a model. | 5 point stars |
| 94 | Multiple layers and overlapping planes. | Non-geometric. |
| 95 | Difficulty of drawing an object. | Multi-part |
| 96 | Geometric complexity is the level of difficulty the design is in respect to CAD. | Isometric circles |
| 97 | N/A | Round and spherical shapes. |
| 98 | The more features, the more complex. | Any shape with numerous faces. |
| 99 | Difficulty of drafting an object. | Things with multiple angles and features. |
| 100 | N/A | Rounded angles and 3D models. |
| 101 | How difficult it is to properly draw an object. | Anything beyond isometric views of 2-D objects (i.e. 3-D anything) |
| 102 | The difficulty of drawing a certain geometric shape in a CAD software. | 3D shapes. |
| 103 | | |
| 104 | | |
| 105 | how many steps it takes to complete a model, having many forces, reference planes and axes | surfaces, free-form complex curves |
| 106 | geometric complexity is a measure of the difficulty in terms of time, effort of modeling a part OR how difficult it is to imagine the steps one would take in recreating the part | volutes, complex surfaces |
| 107 | How hard it is to model | irregular shapes |
| 108 | How simple/complex a drawing is | shaoes that require a lot of detail/very defined |
| 109 | Complex form of geometry (hard to draw) | gears, fillets (intricate detailed objects in general |
| 110 | how difficult or easy a drawing is to draw with CAD software | shapes with complex curves or extrusions |
| 111 | a measure of geometric entropy. Less chaotic would mean more symmetric figures with less complex shapes (less vertices and odd intersecting angles) | swoops, sweeps, non-symmetric revolutions |
| 112 | how complex the shapes of a part drafted in CAD are | irregular or non symmetric ones |
| 113 | geometries that are tough or time consuming to model in CAD | Curved surfaces |
| 114 | complexity would probably refer to how many steps it would take to acquire the final product | sheres |
| 115 | The difficulty of modeling an object with a CAD software | shapes with a changing cross section cross section or things involving sweeps |

| | | |
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| 116 | it is the level of difficulty to model | shapes that are not basic, where you have to flow from one shape to another. Sweep commands |
| 117 | How difficult an objects dimension and shape is to model electronically | curves/non uniform surfaces |
| 118 | The difficulty of reproducing an object in CAD environment | complex curves |
| 119 | how many different geometries are involved in a drawing or component and how complicated that geometry is | curved edges or circles. Cutouts changing through a pies |
| 120 | items that are difficult to construct using fundamental knowledge of geometry | threads |
| 121 | level of difficulty of drawing an object | complex ones |
| 122 | how complex an object is with respect to the geometric features | curves |
| 123 | visual shapes other than square, circle, triangle for the majority of the part | anything with curves defined by polynomials/functions/etc |
| 124 | No idea | difficult shapes |
| 125 | The relative difficulty of an object to be parametrically modeled | sweeps |
| 126 | honestly have zero clue | 3d objects |
| 127 | confusing and difficult design modeling | non symetric curvy shapes |
| 128 | how detail it is | complex model in any shape |
| 129 | how complicated the geometry is | curved shapes |
| 130 | how difficult it would be to accurately model a given shape or object | have circles, triangles |
| 131 | Geometric complexity means the difficulty related to the drawing. | Isometric shapes with multiple parts. |
| 132 | Blank | Blank |
| 133 | The difficulty of creating a geometric shape in CAD. | Rounded out shapes. |
| 134 | How hard a part is to model within a CAD program | Compound curves, Internal tapered and splined objects |
| 135 | how difficult or easy it is to model the geometry in CAD | particular or intricate drawings that cannot be represented by simple geometries |
| 136 | How complex a shape looks | shapes wih many bumps and valleys |
| 137 | 3d graphic desiged, to graphically align your geometries | N/A |
| 138 | geometric complexity means the geometric dimensions and in depth analysis of a structure on CAD | shapes that have to do with holes or circles |
| 139 | The difficuly level of creating a geometric object in AutoCAD | Three dimensional circles and Arcs |
| 140 | How intricate a shape or model is | shapes with lots of internal, hidden components |
| 141 | A very difficult item with many shape | organize shapes |

| | | |
|---|---|---|
| 142 | I suppose geometric complexity means how precise parts are made | difficult parts in my opinion is anything that requires lofting or multiple planes with 3d surface extrusions |
| 143 | how intricate the shape is being made | irregular shapes |
| 144 | length of time and effort to get the shape or project that was wanted | anything that requires depth, has a lot of faces |
| 145 | A model that would take a lot of time to create or could be difficult to make | complex real world objects are difficult |
| 146 | CAD is able to form perfect complex shapes with its programming | havent done a lot of shapes yet but maybe anything harder than a cylinder |
| 147 | A level of how complex an object or shape is | Spheres |
| 148 | How intricate the design of the object is | 3D shapes b/c I have no idea how |
| 149 | how hard it is to represent a shape or create a shape or understand what the shape you are trying to create | rounded edges |
| 150 | Shapes/objects with irregularities and detailed dimensions | detailed/irregular shapes with "geometric Complexity" |
| 151 | the difficulty an object has in being portrayed through a program like AUTOCAD | many crevices, corners, faces and moving parts |
| 152 | how difficult an object is to portray geometric in a CAD system | circular shapes are most difficult |
| 153 | The complex design of an object | shapes with curves and holes |
| 154 | how difficult an object is to recreate using CAD | Irregular shapes. With smooth corners |
| 155 | how complex the shapes used in the course are | objects with a lot of holes |
| 156 | Geometric shapes that are complicated to display in CAD | Spheres, rounded of 3-dimentional objects |
| 157 | Figures that have different parts and need time to be constructed | anything other than a circle, quare, triangle, that needs knowledge of the program |
| 158 | when you have many geometric shapes put together to form one object | anything with rounded edges or small, specific details/objects within a larger obejct |
| 159 | a shape that is hard to draw using CAD | shapes like circles, cylinder attached to something else |
| 160 | it means how not geometric an object is | free form curves and not uniform sloping surfaces |
| 161 | How complex the geometric shape the object is and how many dimensions are needed | bolts, objects with holes inside |
| 162 | Being able to define any shape using AutoCAD | spheres |
| 163 | How technically involved an object or drawing is in accordance with its views and layers | any irregular shapes or holes |
| 164 | The degree of detail required to accurately create or draw an object | irregular figures, semi-circles |
| 165 | geometric complexity means the difficulty with which it takes to complrehend the model for which you are looking at or designing | cylinders and arches |

| | | |
|---|---|---|
| **166** | Objects of all different dimensions, shapes, and sizes | Blank |
| **167** | What? | ?..Just learned basic CAD features |
| **168** | The degree of difficulty a shape or objecthas when trying to design it in CAD | something with multiple holes/chambers that are hallowed out |
| **169** | Geometric Complexity is the degree of geometric shapes/lines, curves, etc. within a drawing | the topography of earth |
| **170** | Hard to create | geometric domes |
| **171** | Shapes that have difficult views to model | most shapes with multiple holes |
| **172** | Couldn't Read | Couldn't Read |

# APPENDIX D: Study Participant Survey Results

## Table D-1: Study Participants' Survey Results

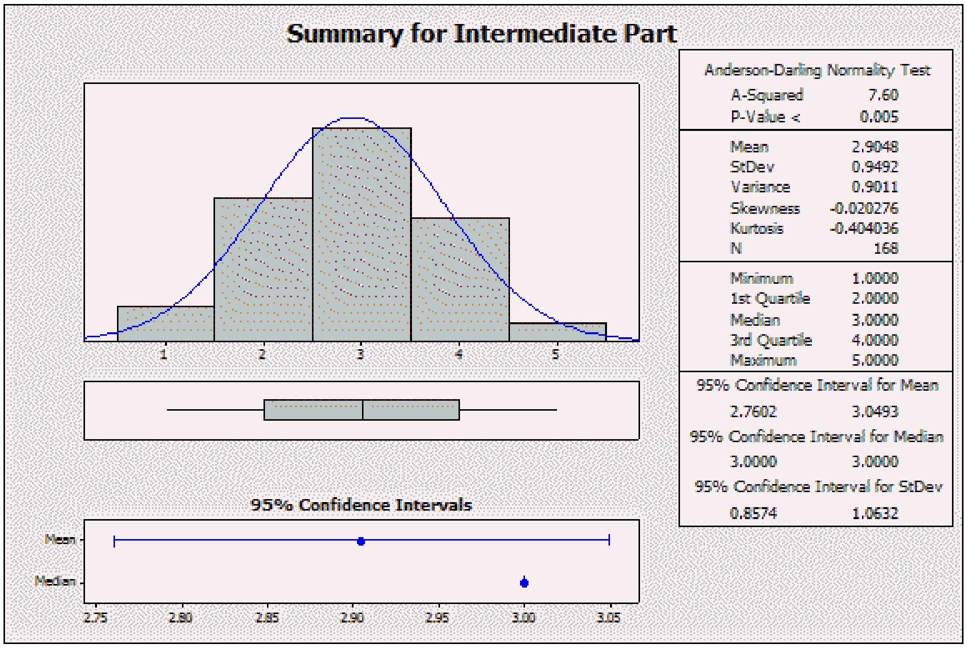
| Student No. | Question 1 | Question 2 | Question 3 | Question 4 | Question 5 | Question 6 | Question 7 | Question 8 | Question 9 | Question 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 3 | 1 | 4 | 1 | 5 | 2 | 3 | 1 | 3 |
| 2 | 1 | 3 | 1 | 4 | 1 | 4 | 1 | 2 | 1 | 3 |
| 3 | 3 | 3 | 1 | 5 | 1 | 5 | 3 | 4 | 1 | 4 |
| 4 | 3 | 4 | 2 | 4 | Blank | 5 | 2 | 4 | 1 | 4 |
| 5 | 1 | 2 | 1 | 3 | 1 | 4 | 1 | 2 | 1 | 2 |
| 6 | 3 | 3 | 1 | 4 | 2 | 5 | 2 | 3 | 1 | 3 |
| 7 | 2 | 3 | 1 | 2 | 1 | 5 | 1 | 3 | 1 | 4 |
| 8 | 3 | 4 | 1 | 4 | 1 | 5 | 1 | 3 | 1 | 3 |
| 9 | 3 | 4 | 1 | 2 | 2 | 4 | 1 | 4 | 1 | 2 |
| 10 | 2 | 4 | 1 | 4 | 2 | 5 | 1 | 4 | 1 | 5 |
| 11 | 2 | 3 | 1 | 4 | 1 | 5 | 1 | 3 | 1 | 3 |
| 12 | 2 | 3 | 1 | 3 | 1 | 5 | 1 | 3 | 1 | 4 |
| 13 | 4 | 5 | 1 | 4 | 2 | 5 | 2 | 4 | 1 | 4 |
| 14 | 2 | 3 | 1 | 3 | 1 | 4 | 1 | 2 | 1 | 3 |
| 15 | 3 | 3 | 1 | 4 | 1 | 5 | 2 | 3 | 1 | 4 |
| 16 | 3 | 4 | 1 | 5 | 2 | 5 | 2 | 4 | 1 | 4 |
| 17 | 2 | 4 | 1 | 3 | 2 | 5 | 2 | 3 | 1 | 4 |
| 18 | 4 | 5 | 1 | 3 | 1 | 5 | 1 | 2 | 1 | 5 |
| 19 | 4 | 5 | 2 | 4 | 2 | 5 | 2 | 4 | 1 | 4 |
| 20 | 1 | 2 | 2 | 3 | 1 | 4 | 1 | 2 | 1 | 3 |
| 21 | 2 | 2 | 1 | 3 | 1 | 4 | 1 | 2 | 1 | 3 |
| 22 | 2 | 3 | 1 | 4 | 2 | 5 | 2 | 3 | 1 | 3 |
| 23 | 3 | 3 | 1 | 3 | 1 | 4 | 2 | 3 | 1 | 4 |
| 24 | 2 | 4 | 1 | 5 | 2 | 5 | 2 | 5 | 1 | 5 |
| 25 | 3 | 5 | 1 | 5 | 1 | 5 | 2 | 4 | 1 | 4 |
| 26 | 2 | 3 | 1 | 3 | 1 | 4 | 1 | 3 | 1 | 5 |
| 27 | 2 | 3 | 2 | 3 | 1 | 4 | 1 | 2 | 1 | 3 |
| 28 | 2 | 3 | 2 | 3 | 1 | 5 | 1 | 4 | 1 | 4 |
| 29 | 3 | 4 | 1 | 5 | 1 | 5 | 1 | 3 | 1 | 4 |
| 30 | 2 | 2 | 1 | 3 | 1 | 4 | 1 | 2 | 1 | 3 |
| 31 | 1 | 4 | 1 | 4 | 1 | 5 | 1 | 3 | 1 | 3 |
| 32 | 3 | 4 | 1 | 4 | 1 | 5 | 2 | 4 | 1 | 4 |
| 33 | 4 | 4 | 1 | 5 | 1 | 5 | 3 | 4 | 1 | 3 |
| 34 | 4 | 3 | 1 | 4 | 2 | 5 | 2 | 4 | 1 | 3 |
| 35 | 3 | 3 | 1 | 4 | 1 | 5 | 1 | 5 | 1 | 5 |
| 36 | 2 | 3 | 3 | 4 | 2 | 4 | 2 | 4 | 1 | 3 |
| 37 | 3 | 4 | 2 | 5 | 2 | 5 | 3 | 4 | 2 | 4 |
| 38 | 3 | 2 | 1 | 3 | 1 | 5 | 1 | 4 | 1 | 3 |
| 39 | 2 | 2 | 1 | 3 | 1 | 4 | 1 | 2 | 1 | 3 |
| 40 | 3 | 5 | 1 | 4 | 1 | 5 | 2 | 3 | 1 | 3 |
| 41 | 2 | 2 | 1 | 3 | 1 | 5 | 1 | 3 | 1 | 4 |
| 42 | 3 | 4 | 1 | 5 | 1 | 5 | 1 | 4 | 1 | 4 |
| 43 | 3 | 3 | 1 | 4 | 1 | 5 | 2 | 3 | 1 | 4 |
| 44 | 4 | 4 | 4 | 5 | 2 | 5 | 2 | 4 | 1 | 4 |
| 45 | 3 | 3 | 1 | 4 | 1 | 5 | 1 | 4 | 1 | 4 |
| 46 | 3 | 4 | 2 | 4 | 1 | 5 | 3 | 4 | 1 | 3 |
| 47 | 3 | 3 | 5 | 3 | 1 | 5 | 1 | 3 | 1 | 3 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 48 | 2 | 2 | 3 | 4 | 1 | 5 | 1 | 4 | 1 | 5 |
| 49 | 2 | 3 | 1 | 4 | 1 | 5 | 1 | 4 | 1 | 4 |
| 50 | 3 | 4 | 1 | 3 | 1 | 5 | 1 | 3 | 1 | 3 |
| 51 | 2 | 3 | 1 | 4 | 2 | 5 | 2 | 3 | 1 | 3 |
| 52 | 3 | 3 | 1 | 4 | 1 | 5 | 2 | 3 | 1 | 3 |
| 53 | 4 | 4 | 2 | 3 | 1 | 5 | 2 | 4 | 1 | 4 |
| 54 | 3 | 3 | 1 | 3 | 2 | 5 | 1 | 4 | 1 | 5 |
| 55 | 2 | 3 | 1 | 4 | 1 | 5 | 2 | 4 | 1 | 3 |
| 56 | 5 | 5 | 1 | 5 | 3 | 5 | 3 | 5 | 1 | 4 |
| 57 | 4 | 5 | 1 | 4 | 2 | 5 | 2 | 4 | 1 | 3 |
| 58 | 4 | 3 | 1 | 5 | 2 | 5 | 2 | 3 | 1 | 3 |
| 59 | 3 | 4 | 1 | 4 | 2 | 5 | 3 | 3 | 2 | 4 |
| 60 | 5 | 5 | 2 | 5 | 1 | 5 | 4 | 5 | 1 | 5 |
| 61 | 4 | 4 | 4 | 5 | 2 | 5 | 1 | 4 | 2 | 4 |
| 62 | 3 | 4 | 2 | 3 | 1 | 5 | 2 | 3 | 1 | 2 |
| 63 | 4 | 4 | 2 | 3 | 2 | 4 | 2 | 3 | 2 | 3 |
| 64 | 3 | 4 | 2 | 5 | 2 | 5 | 2 | 5 | 1 | 4 |
| 65 | 4 | 3 | 1 | 3 | 2 | 5 | 2 | 4 | 2 | 4 |
| 66 | 5 | 5 | 1 | 5 | 2 | 5 | 3 | 5 | 1 | 4 |
| 67 | 3 | 4 | 1 | 5 | 1 | 5 | 2 | 4 | 1 | 4 |
| 68 | 4 | 4 | 1 | 4 | 2 | 5 | 2 | 4 | 1 | 4 |
| 69 | 3 | 4 | 1 | 4 | 2 | 5 | 2 | 4 | 1 | 4 |
| 70 | 4 | 4 | 2 | 5 | 2 | 5 | 2 | 4 | 1 | 5 |
| 71 | 4 | 5 | 2 | 3 | 1 | 5 | 2 | 4 | 1 | 4 |
| 72 | 3 | 3 | 2 | 4 | 2 | 4 | 3 | 3 | 2 | 3 |
| 73 | 4 | 5 | 1 | 4 | 2 | 5 | 3 | 5 | 1 | 4 |
| 74 | 4 | 4 | 1 | 5 | 2 | 5 | 3 | 4 | 1 | 3 |
| 75 | 3 | 4 | 1 | 5 | 1 | 5 | 2 | 3 | 1 | 5 |
| 76 | 2 | 3 | 1 | 3 | 2 | 5 | 2 | 3 | 1 | 4 |
| 77 | 2 | 2 | 1 | 4 | 1 | 5 | 1 | 3 | 1 | 3 |
| 78 | 2 | 3 | 1 | 3 | 1 | 4 | 3 | 4 | 1 | 3 |
| 79 | 3 | 2 | 1 | 2 | 1 | 5 | 1 | 3 | 1 | 3 |
| 80 | 2 | 4 | 1 | 3 | 1 | 4 | 2 | 4 | 1 | 3 |
| 81 | 1 | 1 | 1 | 3 | 2 | 5 | 1 | 4 | 1 | 4 |
| 82 | 3 | 3 | 1 | 5 | 2 | 5 | 1 | 4 | 1 | 5 |
| 83 | 3 | 3 | 1 | 4 | 2 | 5 | 2 | 4 | 1 | 4 |
| 84 | 1 | 1 | 1 | 3 | 1 | 4 | 1 | 3 | 1 | 3 |
| 85 | 2 | 2 | 1 | 3 | 1 | 4 | 1 | 3 | 1 | 3 |
| 86 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 87 | 2 | 4 | 1 | 4 | 2 | 5 | 2 | 4 | 2 | 4 |
| 88 | 3 | 4 | 1 | 4 | 2 | 5 | 2 | 5 | 1 | 4 |
| 89 | 3 | 4 | 1 | 5 | 1 | 5 | 2 | 4 | 1 | 3 |
| 90 | 2 | 3 | 1 | 3 | 1 | 5 | 1 | 3 | 1 | 4 |
| 91 | 3 | 3 | 1 | 4 | 1 | 5 | 1 | 4 | 1 | 4 |
| 92 | 4 | 5 | 3 | 4 | 1 | 5 | 2 | 3 | 1 | 4 |
| 93 | 2 | 2 | 1 | 4 | 1 | 5 | 1 | 3 | 1 | 4 |
| 94 | 3 | 4 | 1 | 4 | 2 | 5 | 2 | 5 | 2 | 4 |
| 95 | 2 | 3 | 1 | 4 | 1 | 4 | 2 | 4 | 1 | 3 |
| 96 | 3 | 4 | 1 | 5 | 2 | 5 | 1 | 4 | 1 | 5 |
| 97 | 3 | 3 | 2 | 4 | 3 | 5 | 2 | 4 | 1 | 4 |
| 98 | 4 | 4 | 2 | 4 | 3 | 5 | 3 | 4 | 1 | 3 |
| 99 | 3 | 2 | 1 | 4 | 2 | 5 | 1 | 3 | 1 | 4 |
| 100 | 4 | 4 | 2 | 3 | 3 | 4 | 3 | 4 | 2 | 3 |
| 101 | 3 | 4 | 1 | 5 | 1 | 5 | 1 | 4 | 1 | 4 |

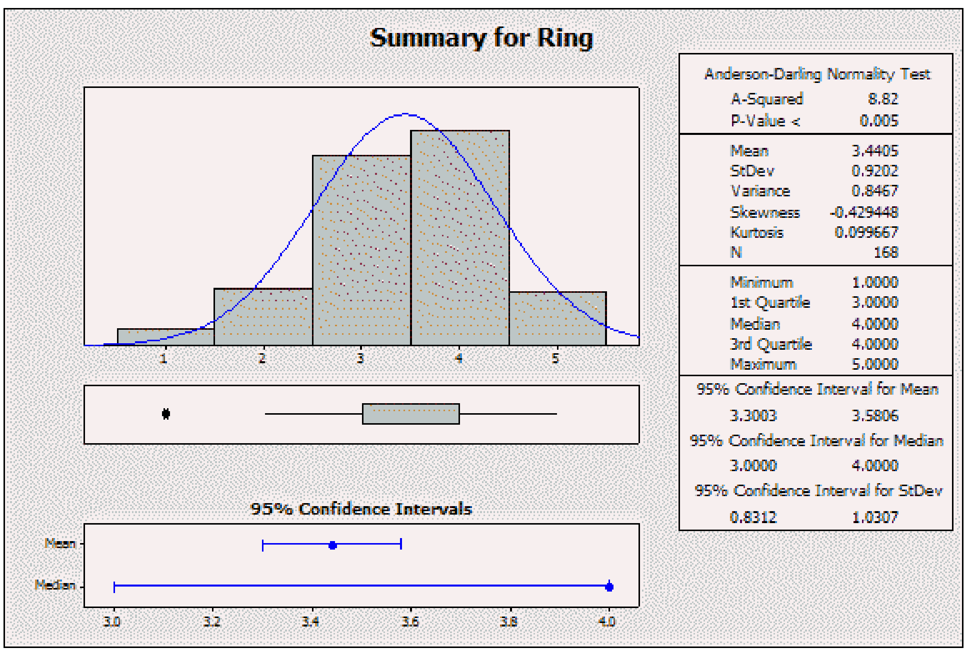
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 102 | 4 | 4 | 2 | 3 | 2 | 4 | 2 | 3 | 2 | 3 |
| 103 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 104 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 105 | 2 | 3 | 1 | 4 | 2 | 5 | 2 | 3.5 | 1 | 3 |
| 106 | 1 | 3 | 2 | 3 | 1 | 5 | 1 | 4 | 1 | 5 |
| 107 | 2 | 4 | 3 | 3 | 1 | 5 | 1 | 4 | 1 | 4 |
| 108 | 3 | 3 | 1 | 5 | 1 | 5 | 2 | 4 | 1 | 5 |
| 109 | 3 | 3 | 5 | 4 | 1 | 5 | 1 | 3 | 1 | 3 |
| 110 | 2 | 4 | 1 | 4 | 1 | 5 | 1 | 4 | 1 | 3 |
| 111 | 2 | 2 | 1 | 3 | 2 | 5 | 1 | 3 | 1 | 4 |
| 112 | 3 | 3 | 1 | 4 | 2 | 5 | 3 | 4 | 1 | 4 |
| 113 | 3 | 3 | 1 | 2 | 1 | 4 | 3 | 5 | 1 | 2 |
| 114 | 3 | 4 | 2 | 5 | 2 | 5 | 2 | 4 | 1 | 5 |
| 115 | 2 | 3 | 1 | 3 | 1 | 4 | 2 | 3 | 1 | 4 |
| 116 | 3 | 3 | 2 | 4 | 1 | 5 | 2 | 4 | 1 | 4 |
| 117 | 2 | 3 | 1 | 4 | 1 | 5 | 1 | 3 | 1 | 4 |
| 118 | 2 | 3 | 1 | 3 | 1 | 5 | 2 | 3 | 1 | 3 |
| 119 | 2 | 3 | 1 | 4 | 1 | 5 | 1 | 4 | 1 | 4 |
| 120 | 1 | 2 | 1 | 3 | 1 | 4 | 1 | 1 | 1 | 2 |
| 121 | 2 | 2 | 1 | 3 | 1 | 4 | 1 | 2 | 1 | 3 |
| 122 | 3 | 4 | 1 | 4 | 2 | 5 | 2 | 4 | 1 | 4 |
| 123 | 1 | 3 | 1 | 4 | 1 | 5 | 1 | 3 | 1 | 4 |
| 124 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 3 |
| 125 | 3 | 4 | 1 | 4 | 2 | 5 | 2 | 4 | 1 | 5 |
| 126 | 3 | 4 | 1 | 4 | 2 | 5 | 2 | 4 | 1 | 3 |
| 127 | 2 | 3 | 1 | 4 | 2 | 5 | 2 | 3 | 1 | 4 |
| 128 | 3 | 4 | 2 | 4 | 2 | 5 | 2 | 4 | 1 | 3 |
| 129 | 3 | 4 | 1 | 3 | 2 | 4 | 2 | 3 | 1 | 4 |
| 130 | 4 | 4 | 1 | 4 | 2 | 5 | 2 | 5 | 1 | 4 |
| 131 | 3 | 4 | 1 | 4 | 3 | 5 | 3 | 4 | 1 | 4 |
| 132 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 |
| 133 | 3 | 3 | 1 | 4 | 2 | 5 | 2 | 4 | 1 | 4 |
| 134 | 2 | 2 | 1 | 3 | 1 | 5 | 2 | 4 | 1 | 3 |
| 135 | 3 | 3 | 2 | 4 | 2 | 5 | 2 | 3 | 1 | 4 |
| 136 | 2 | 3 | 1 | 4 | 2 | 5 | 2 | 4 | 1 | 5 |
| 137 | 4 | 4 | 1 | 1 | 1 | 4 | 2 | 4 | 1 | 3 |
| 138 | 3 | 2 | blank | 4 | blank | 5 | 2 | 4 | 1 | 5 |
| 139 | 4 | 5 | 3 | 4 | 2 | 5 | 3 | 5 | 2 | 3 |
| 140 | 4 | 4 | 1 | 5 | 3 | 5 | 2 | 4 | 1 | 4 |
| 141 | 2 | 4 | 2 | 5 | 2 | 5 | 2 | 5 | 1 | 4 |
| 142 | 2 | 1 | 1 | 3 | 1 | 4 | 1 | 2 | 1 | 3 |
| 143 | 3 | 3 | 1 | 4 | 2 | 5 | 1 | 5 | 1 | 4 |
| 144 | 4 | 4 | 2 | 3 | 2 | 5 | 2 | 5 | 2 | 5 |
| 145 | 3 | 4 | 1 | 4 | 2 | 5 | 2 | 5 | 1 | 4 |
| 146 | 4 | 4 | 1 | 5 | 3 | 5 | 3 | 5 | 2 | 5 |
| 147 | 4 | 3 | 1 | 4 | 2 | 5 | 2 | 4 | 1 | 3 |
| 148 | 3 | 4 | 1 | 4 | 2 | 5 | 2 | 4 | 1 | 3 |
| 149 | 4 | 4 | 1 | 5 | 2 | 5 | 2 | 4 | 1 | 3 |
| 150 | 4 | 4 | 2 | 4 | 2 | 5 | 2 | 4 | 1 | 3 |
| 151 | 4 | 5 | 2 | 5 | 2 | 5 | 3 | 4 | 2 | 4 |
| 152 | 3 | 4 | 2 | 3 | 1 | 5 | 2 | 4 | 1 | 4 |
| 153 | 4 | 3 | 1 | 3 | 2 | 5 | 3 | 4 | 1 | 4 |
| 154 | 4 | 4 | 1 | 5 | 2 | 5 | 3 | 4 | 1 | 5 |
| 155 | 4 | 4 | 1 | 3 | 2 | 5 | 3 | 3 | 1 | 3 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 156 | 3 | 4 | 5 | 4 | 4 | 5 | 3 | 3 | 2 | 4 |
| 157 | 3 | 3 | 1 | 4 | 2 | 5 | 2 | 4 | 1 | 5 |
| 158 | 4 | 5 | 1 | 4 | 3 | 5 | 3 | 5 | 1 | 5 |
| 159 | 3 | 4 | 3 | 4 | 3 | 5 | 3 | 4.5 | 2 | 4 |
| 160 | 2 | 3 | 1 | 3 | 2 | 5 | 2 | 3 | 1 | 5 |
| 161 | 5 | 4 | 1 | 3 | 2 | 5 | 2 | 5 | 2 | 4 |
| 162 | 5 | 4 | 2 | 5 | 2 | 5 | 2 | 4 | 1 | 5 |
| 163 | 4 | 3 | 1 | 5 | 1 | 5 | 1 | 5 | 1 | 4 |
| 164 | 4 | 5 | 1 | 3 | 2 | 5 | 3 | 4 | 1 | 3 |
| 165 | 4 | 4 | 1 | 5 | 1 | 5 | 2 | 5 | 1 | 3 |
| 166 | 3 | 4 | 1 | 4 | 2 | 5 | 3 | 5 | 1 | 4 |
| 167 | 3 | 3 | 1 | 3 | 2 | 4 | 3 | 3 | 1 | 3 |
| 168 | 4 | 4 | 2 | 3 | 3 | 5 | 2 | 4 | 2 | 5 |
| 169 | 2 | 3 | 1 | 4 | 2 | 5 | 2 | 3 | 2 | 3 |
| 170 | 3 | 4 | 1 | 3 | 1 | 4 | 1 | 3 | 1 | 4 |
| 171 | 5 | 5 | 2 | 4 | 3 | 5 | 3 | 5 | 3 | 5 |
| 172 | 5 | 5 | 5 | 5 | 1 | 5 | 1 | 5 | 1 | 5 |

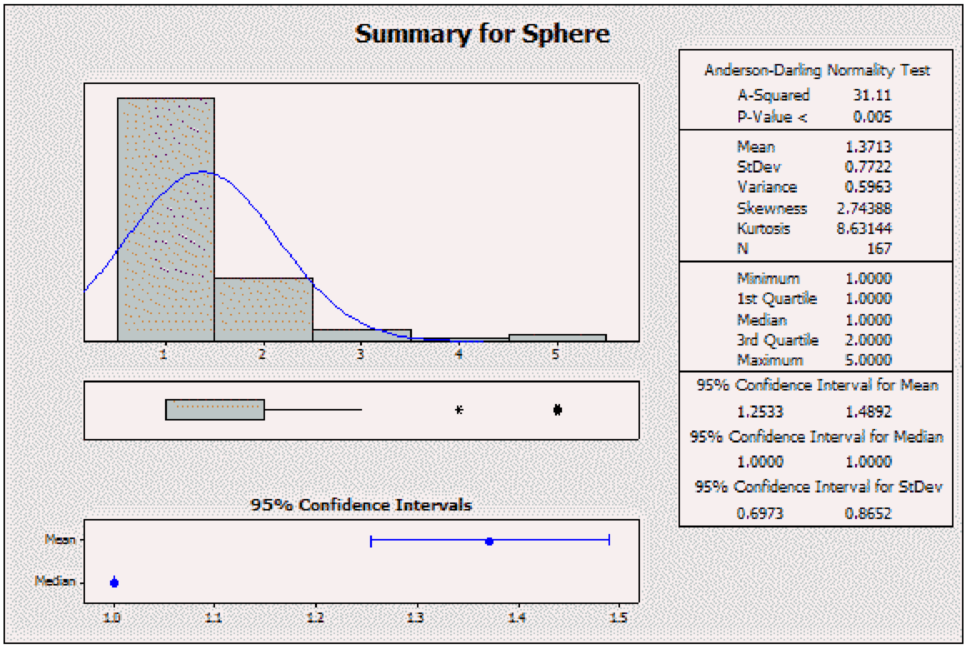
# APPENDIX E: Pictographic Representations for basic statistical analysis



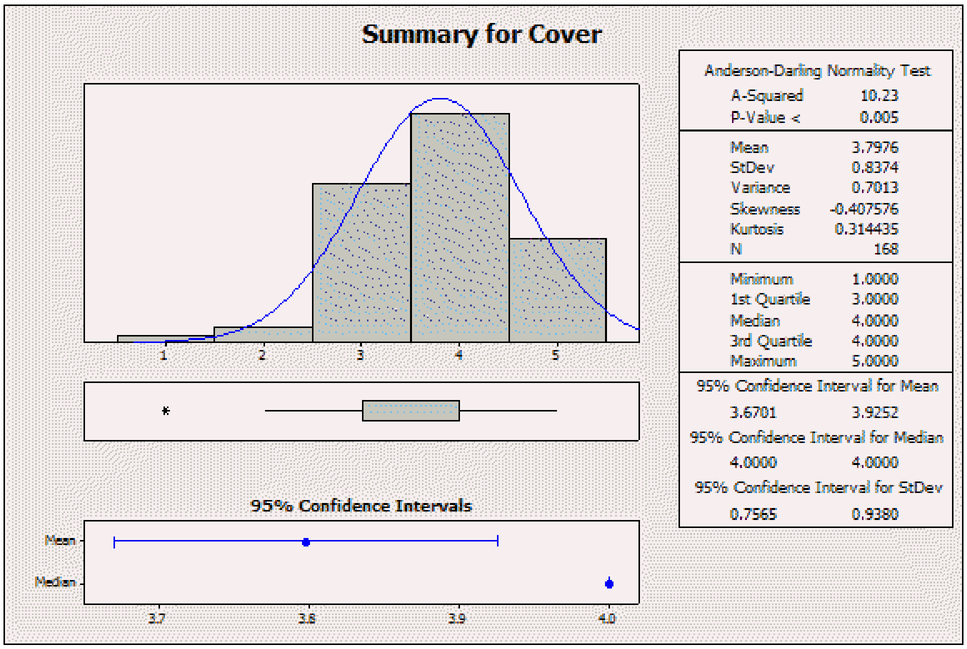

**FigureE1: Basic Statistical Summary of Question1**



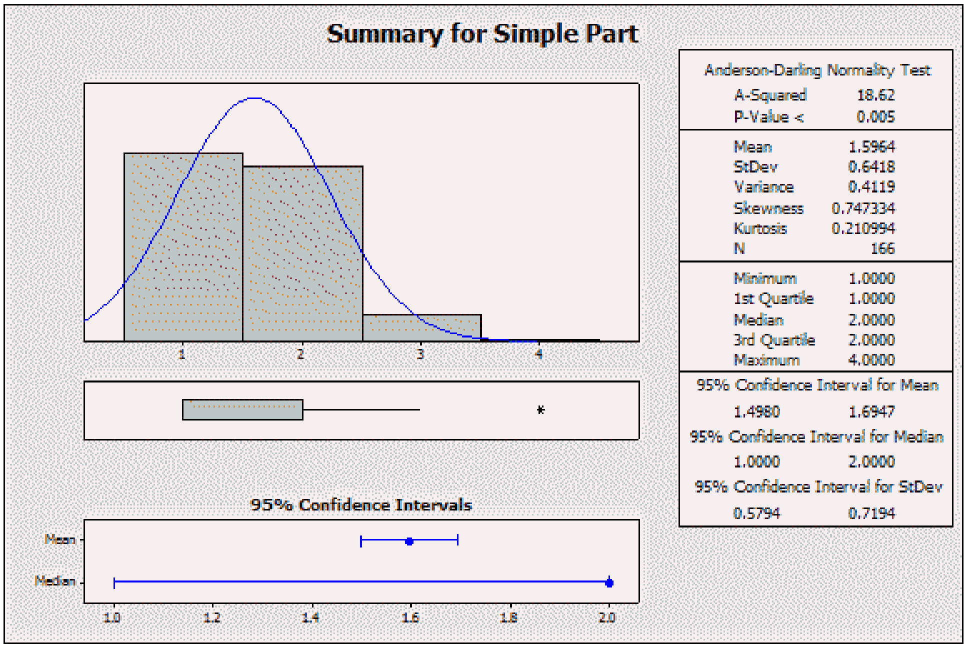

**FigureE2: Basic Statistical Summary of Question2**



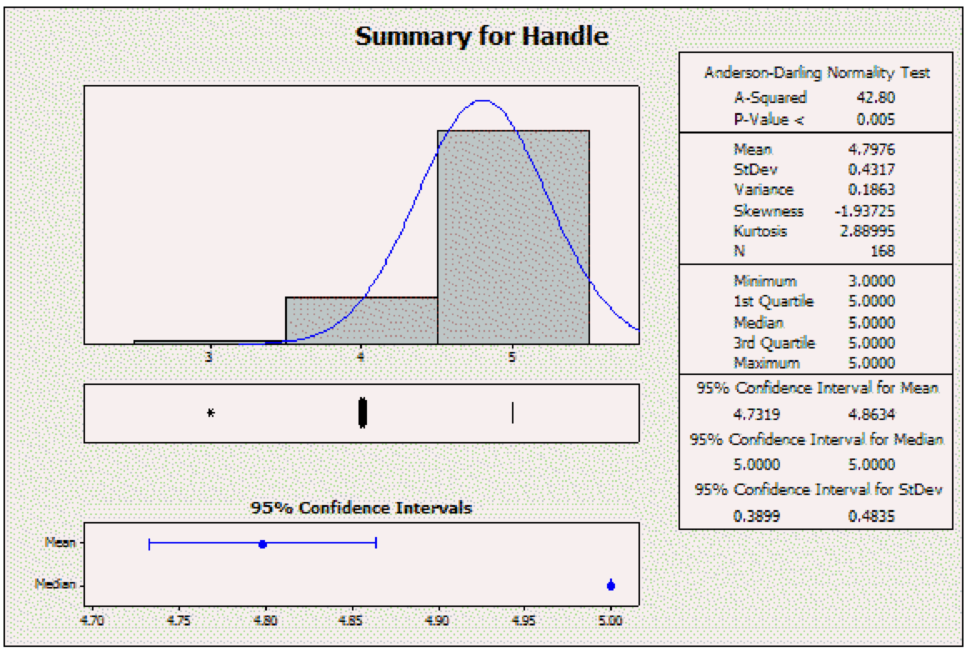

**FigureE3: Basic Statistical Summary of Question3**



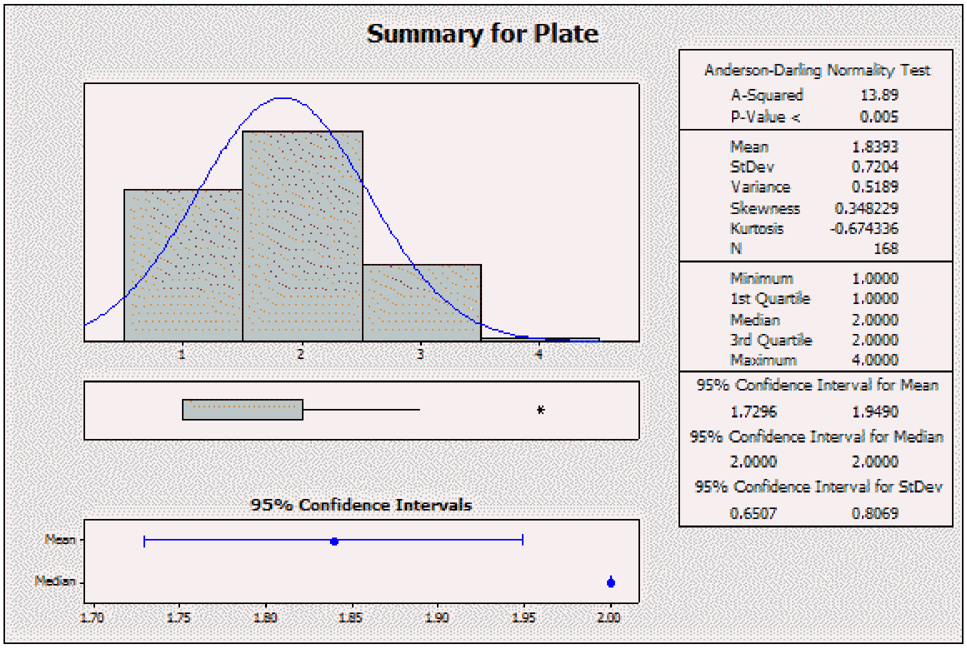

**FigureE4: Basic Statistical Summary of Question4**



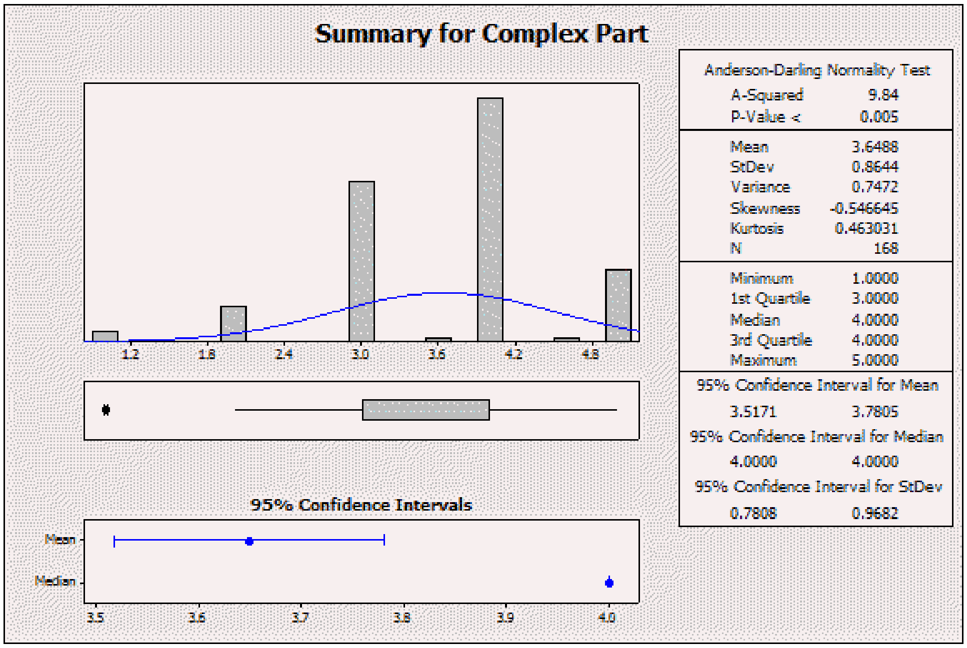

**FigureE5: Basic Statistical Summary of Question5**



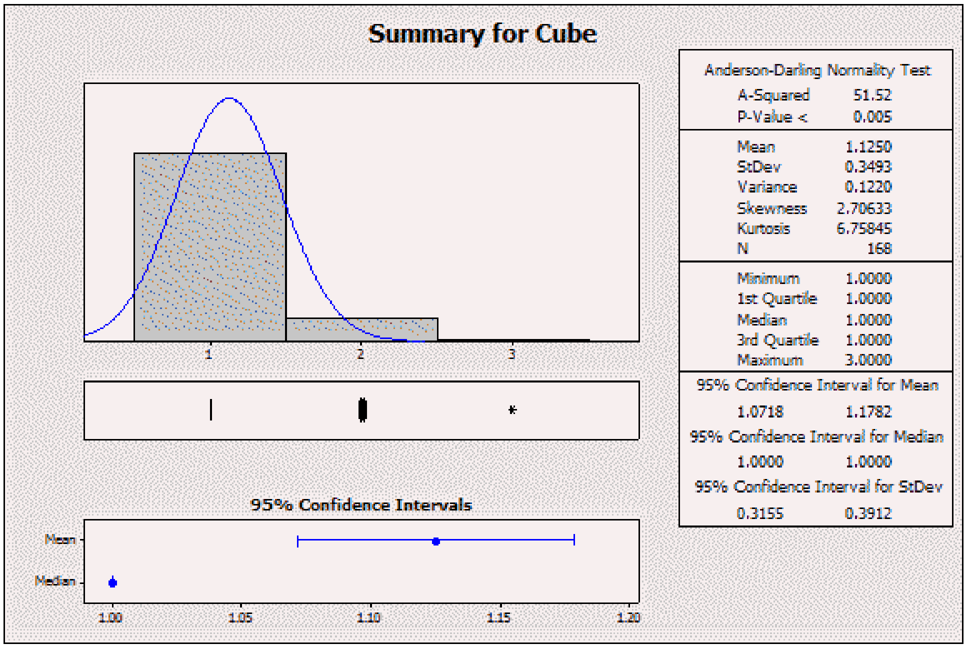

**FigureE6: Basic Statistical Summary of Question6**



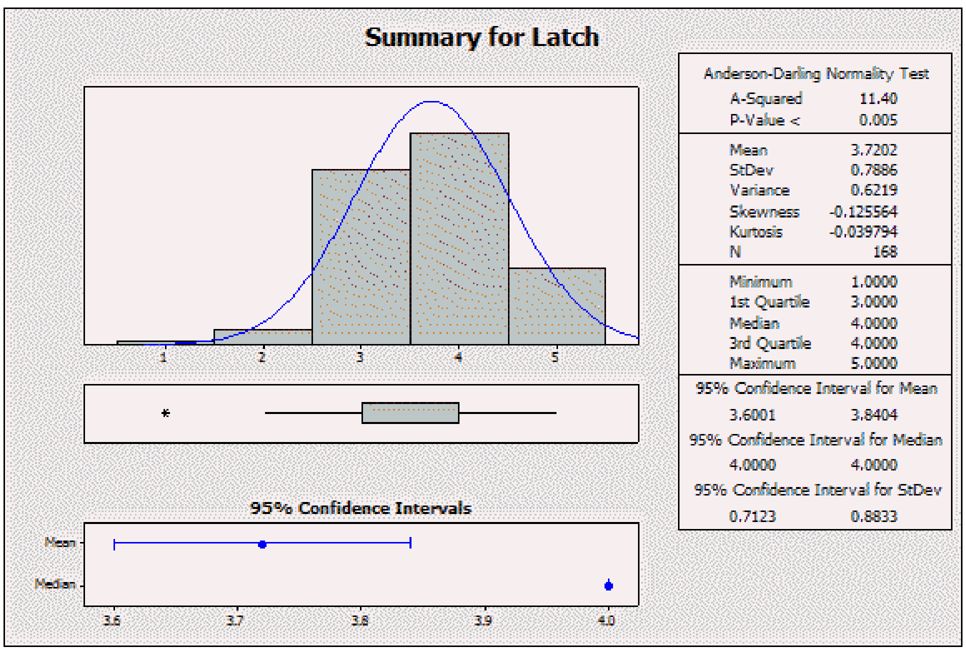

**FigureE7: Basic Statistical Summary of Question7**




**FigureE8: Basic Statistical Summary of Question8**

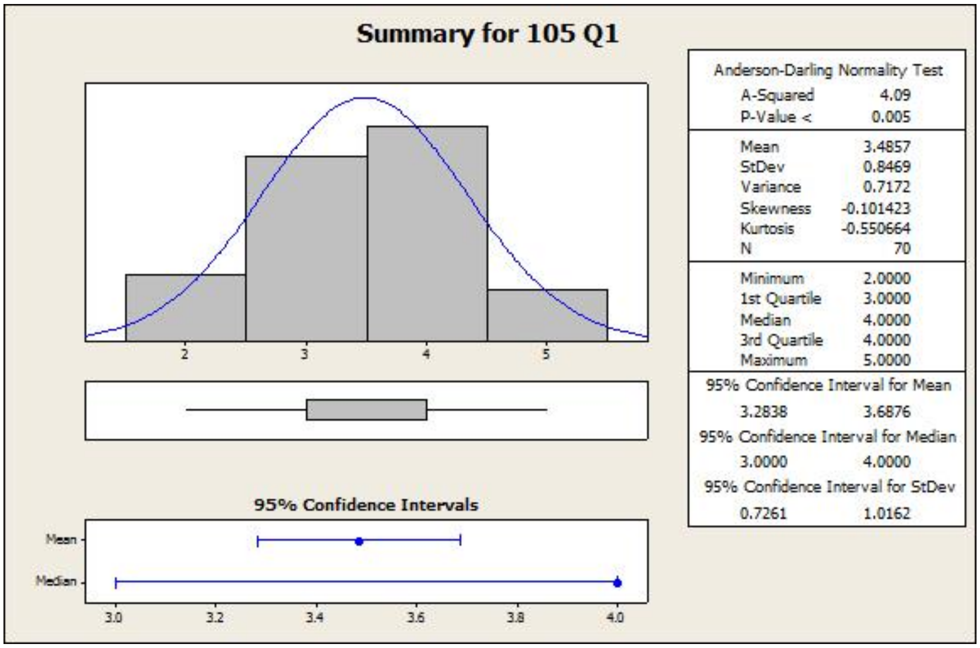



**FigureE9: Basic Statistical Summary of Question9**

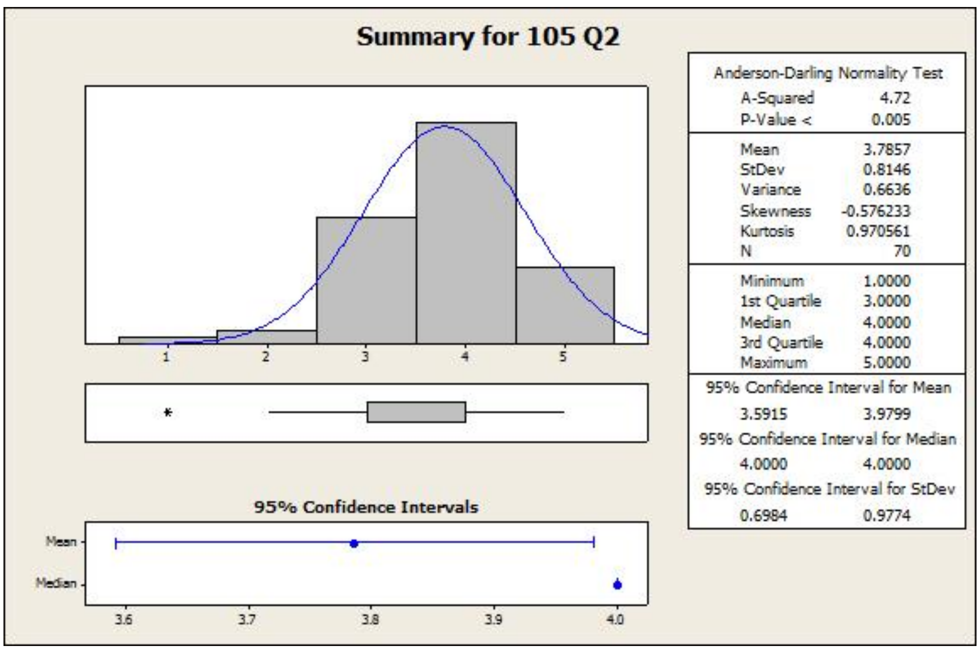



**FigureE10: Basic Statistical Summary of Question10**

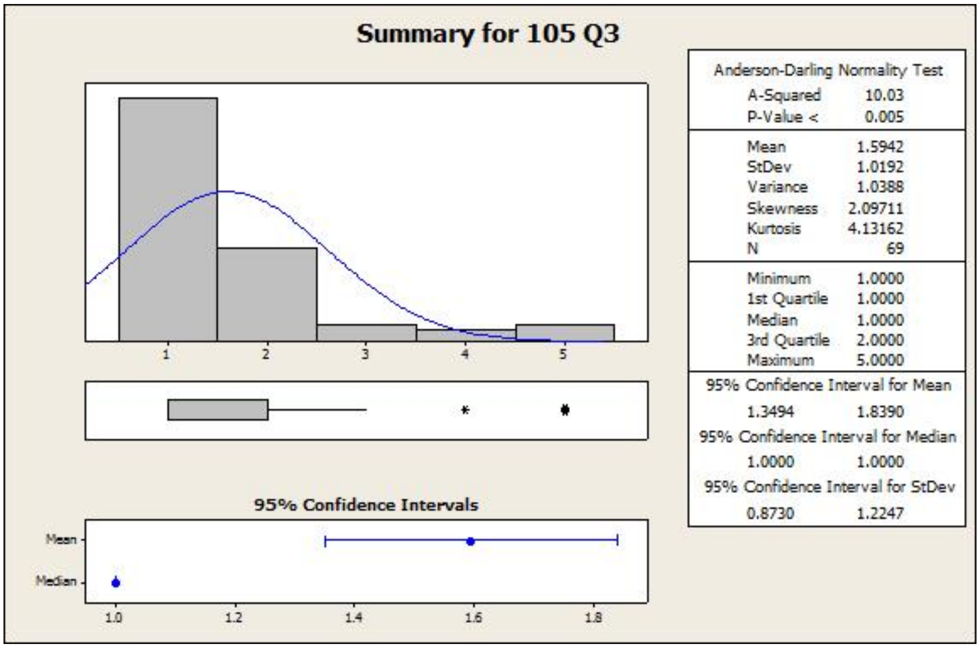
## APPENDIX F: Basic Statistics by Class by Question



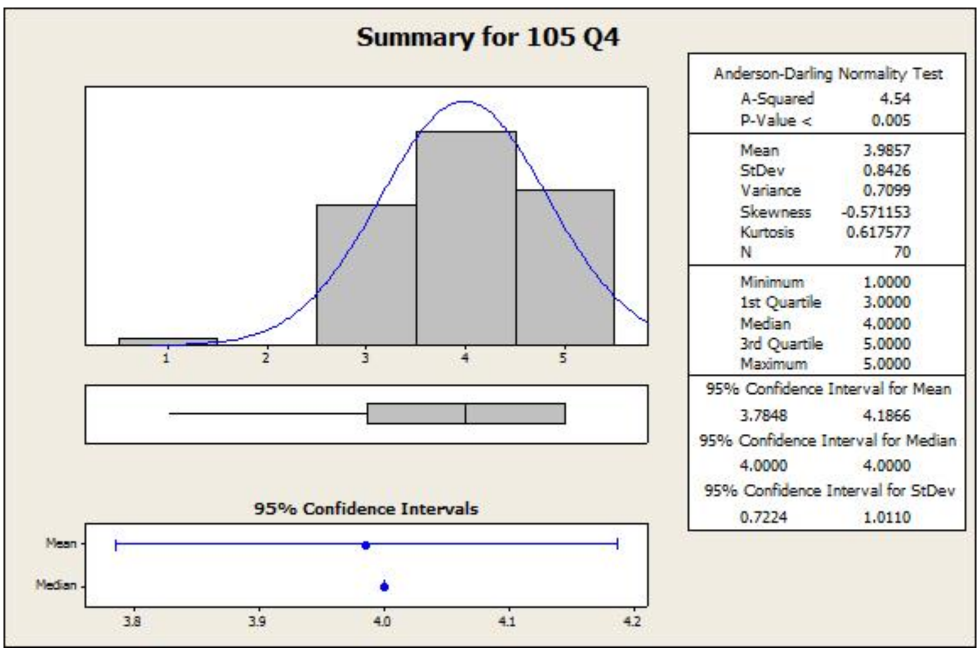

**FigureF1: Basic Statistical Summary of Question1 According to ENDG 105 Students**



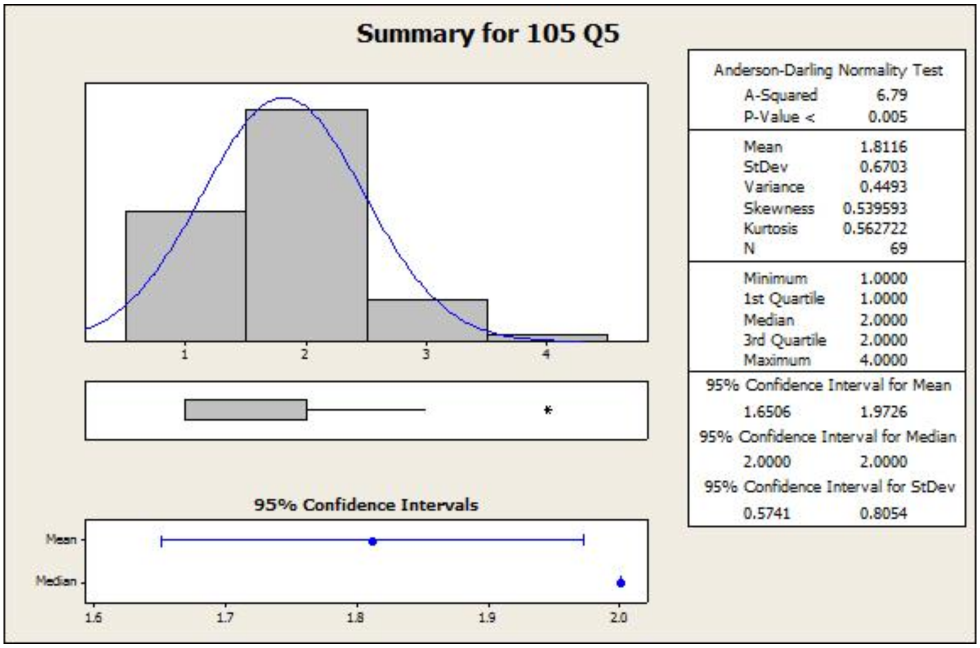

**FigureF2: Basic Statistical Summary of Question2 According to ENDG 105 Students**



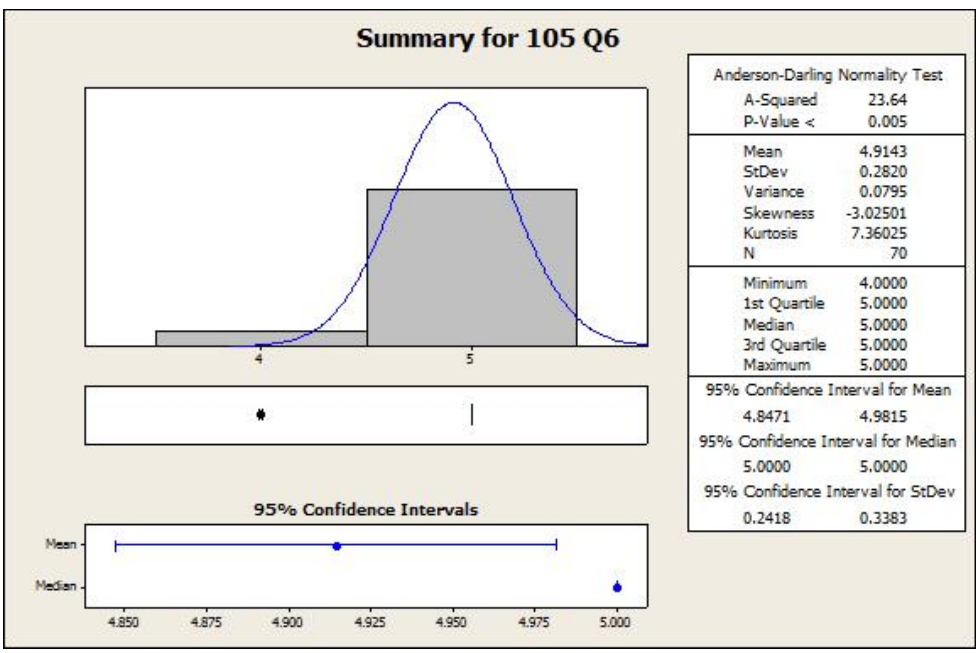

**FigureF3: Basic Statistical Summary of Question3 According to ENDG 105 Students**



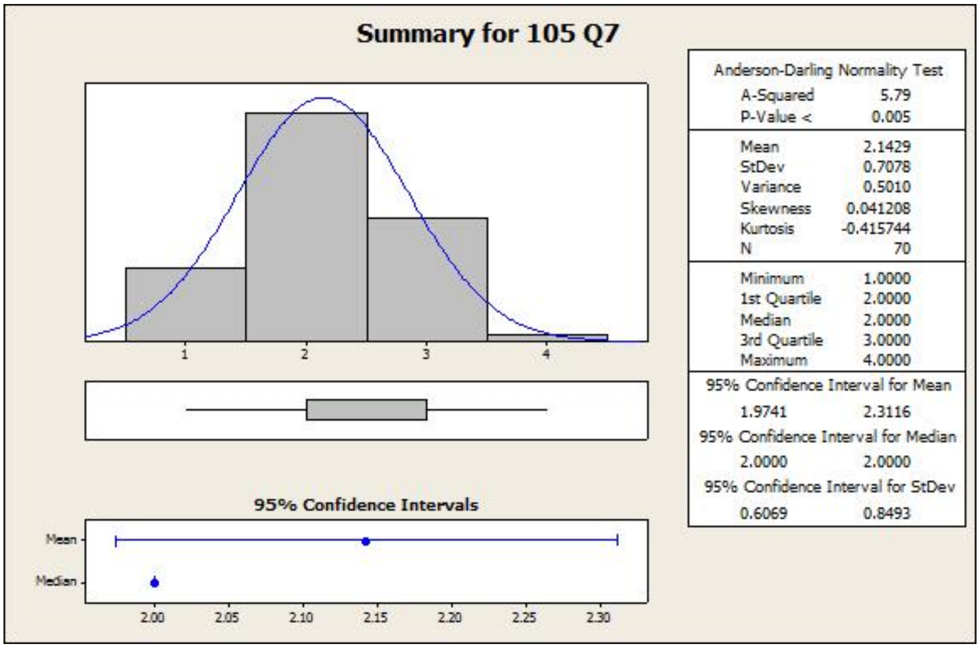

**FigureF4: Basic Statistical Summary of Question4 According to ENDG 105 Students**



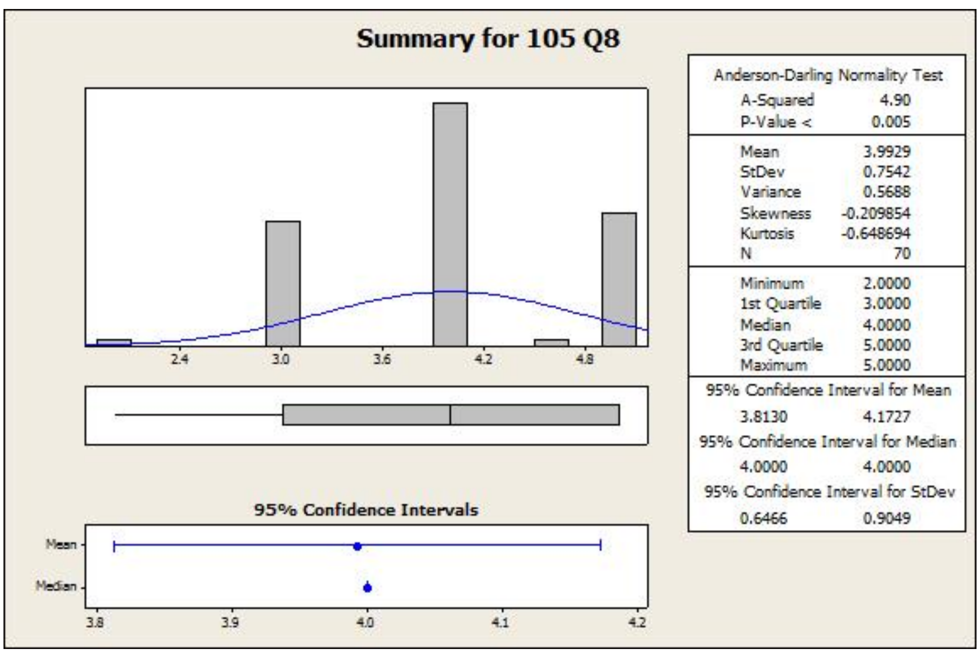

**FigureF5: Basic Statistical Summary of Question5 According to ENDG 105 Students**



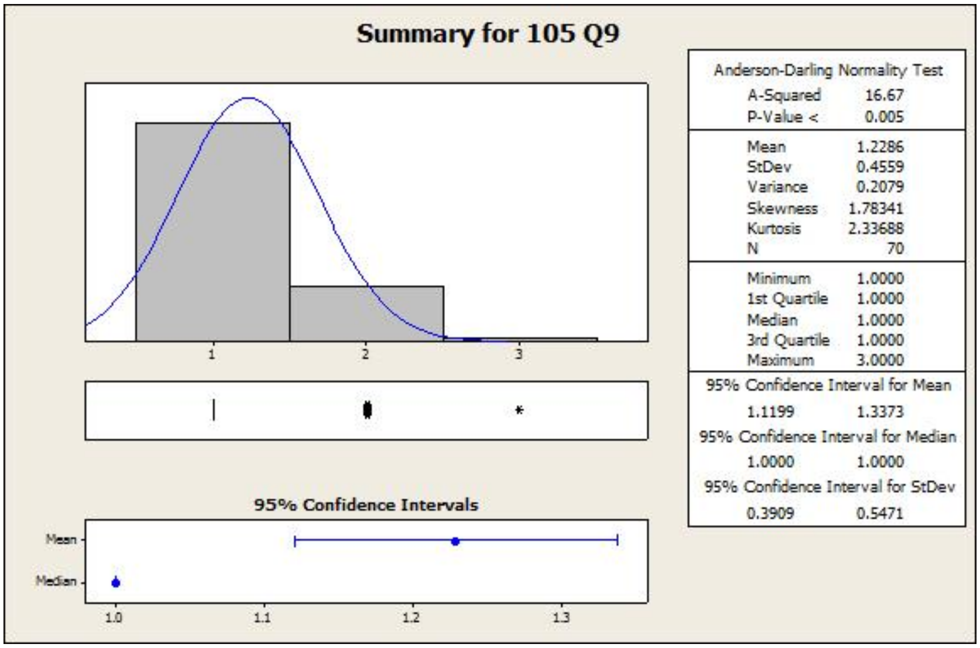

**FigureF6: Basic Statistical Summary of Question6 According to ENDG 105 Students**



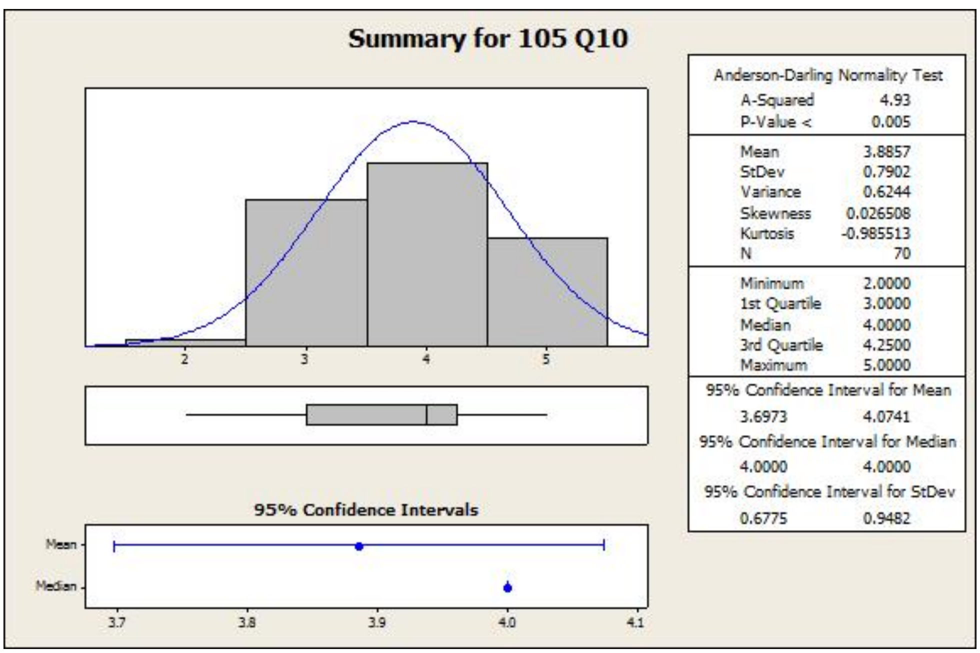

**FigureF7: Basic Statistical Summary of Question7 According to ENDG 105 Students**



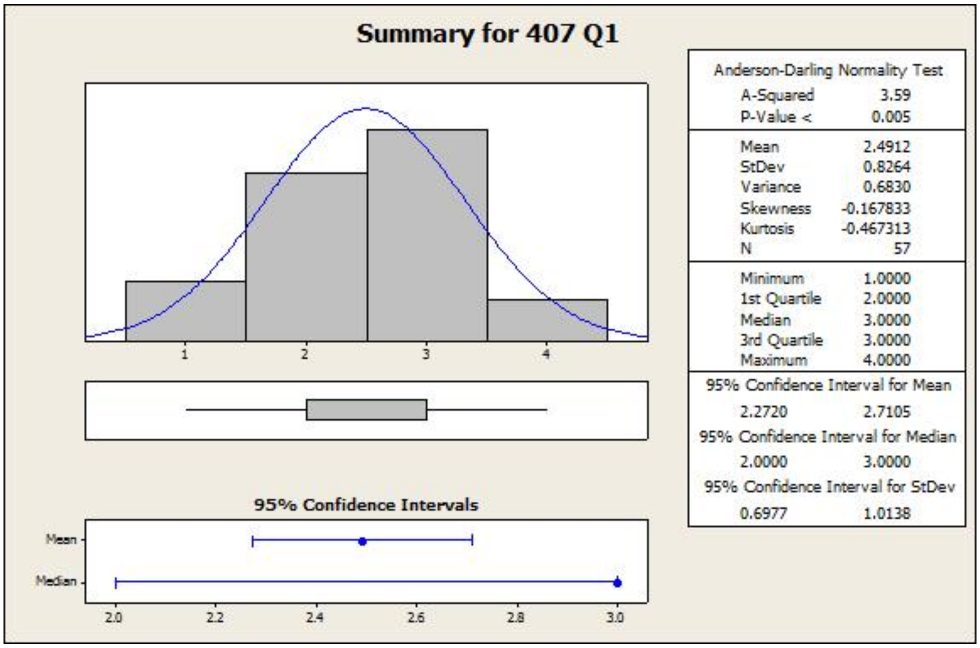

**FigureF8: Basic Statistical Summary of Question8 According to ENDG 105 Students**



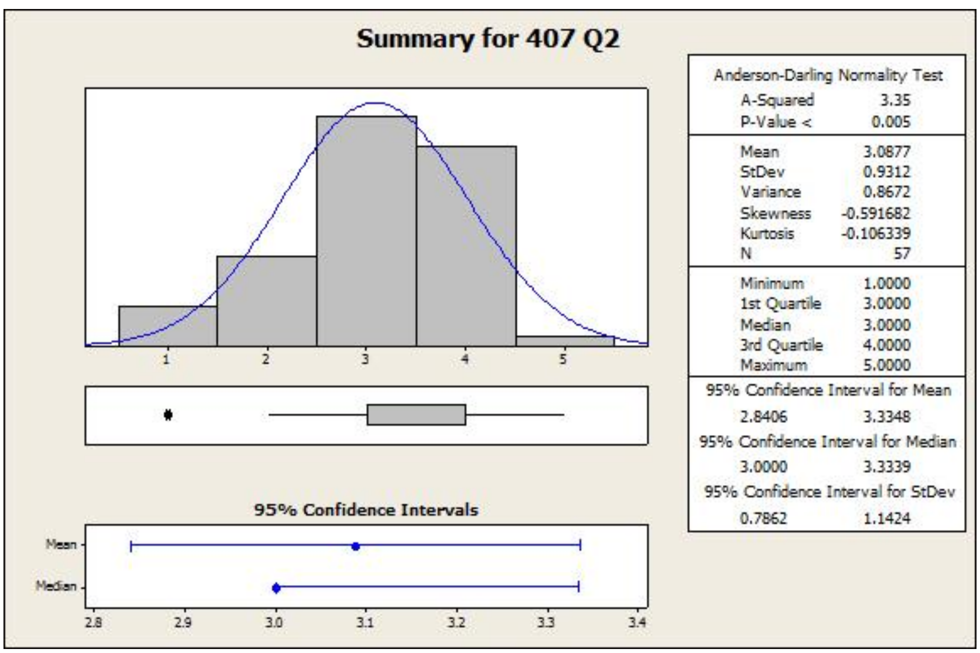

**FigureF9: Basic Statistical Summary of Question9 According to ENDG 105 Students**



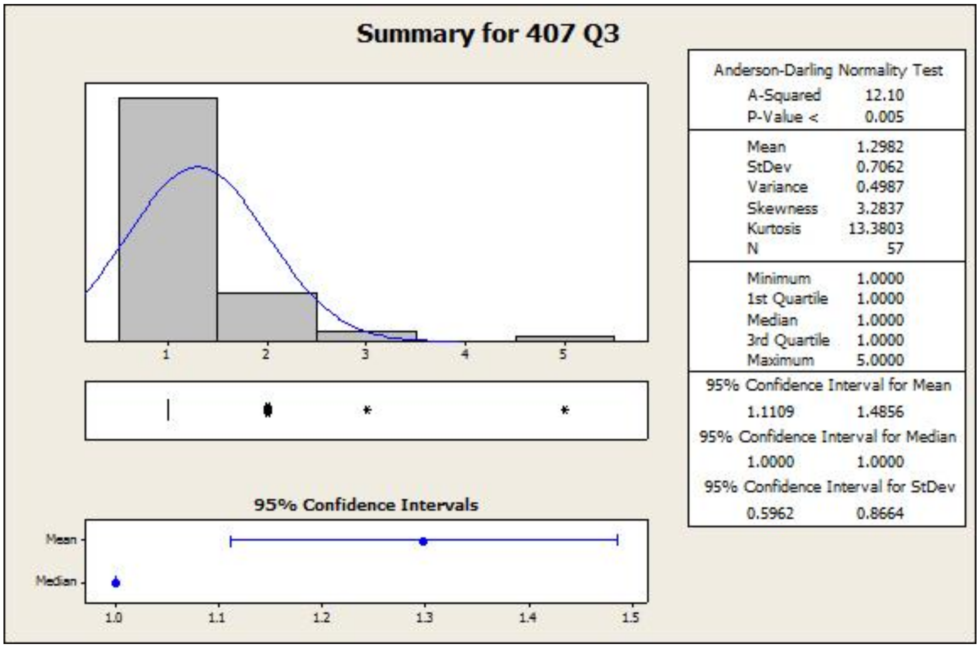

**FigureF10: Basic Statistical Summary of Question10 According to ENDG 105 Students**



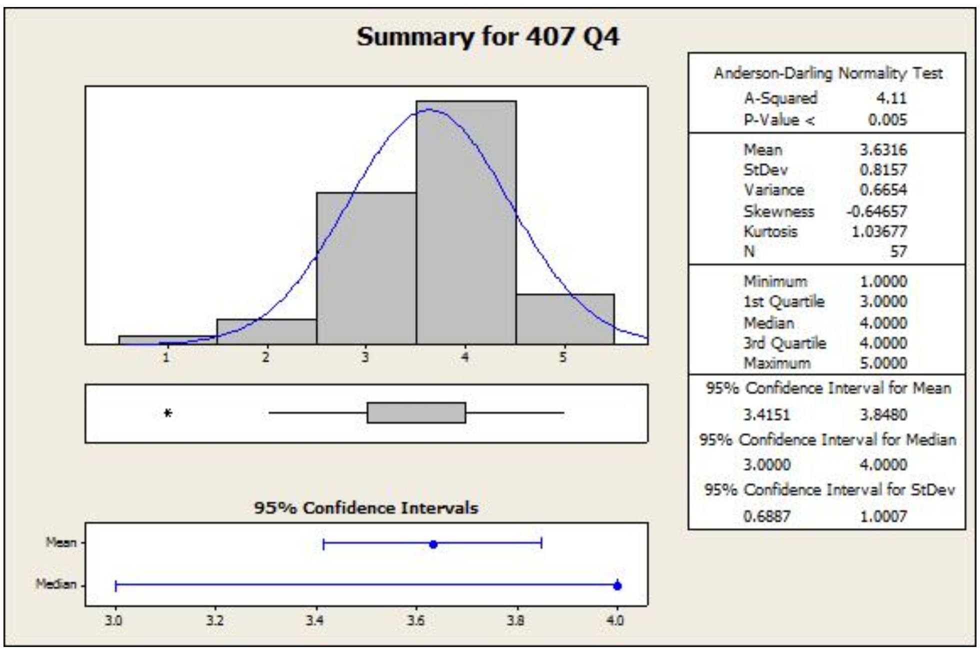

**FigureF11: Basic Statistical Summary of Question1 According to ENDG 407 Students**



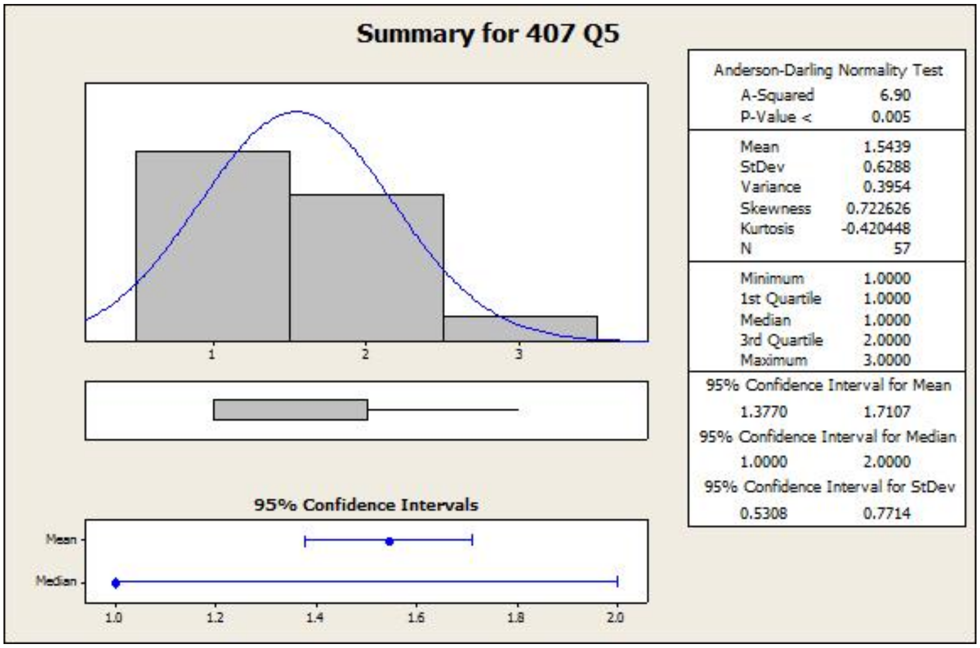

**FigureF12: Basic Statistical Summary of Question2 According to ENDG 407 Students**



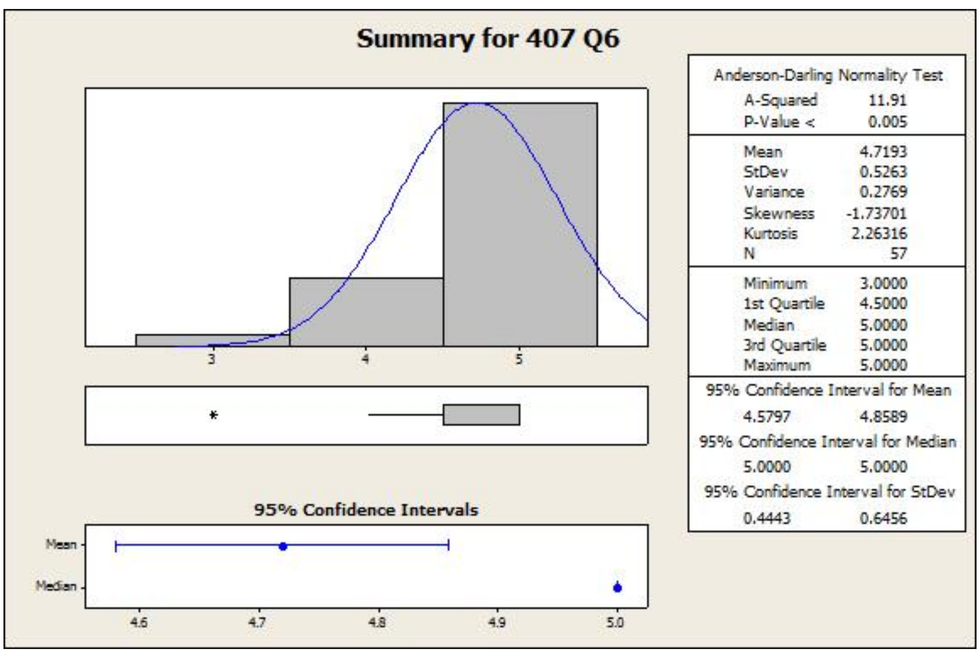

**FigureF13: Basic Statistical Summary of Question3 According to ENDG 407 Students**



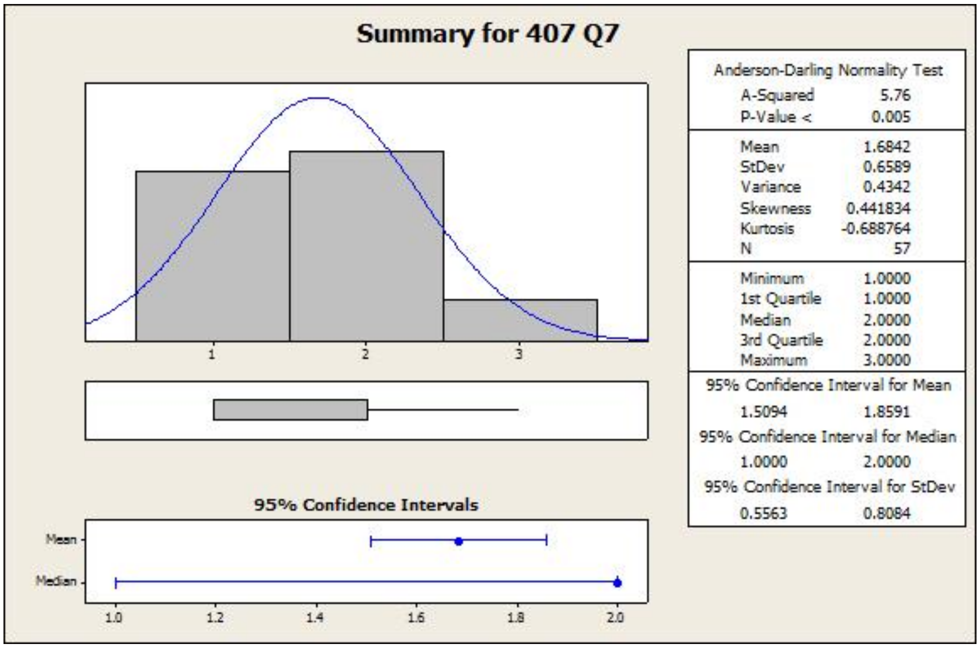

**FigureF14: Basic Statistical Summary of Question4 According to ENDG 407 Students**



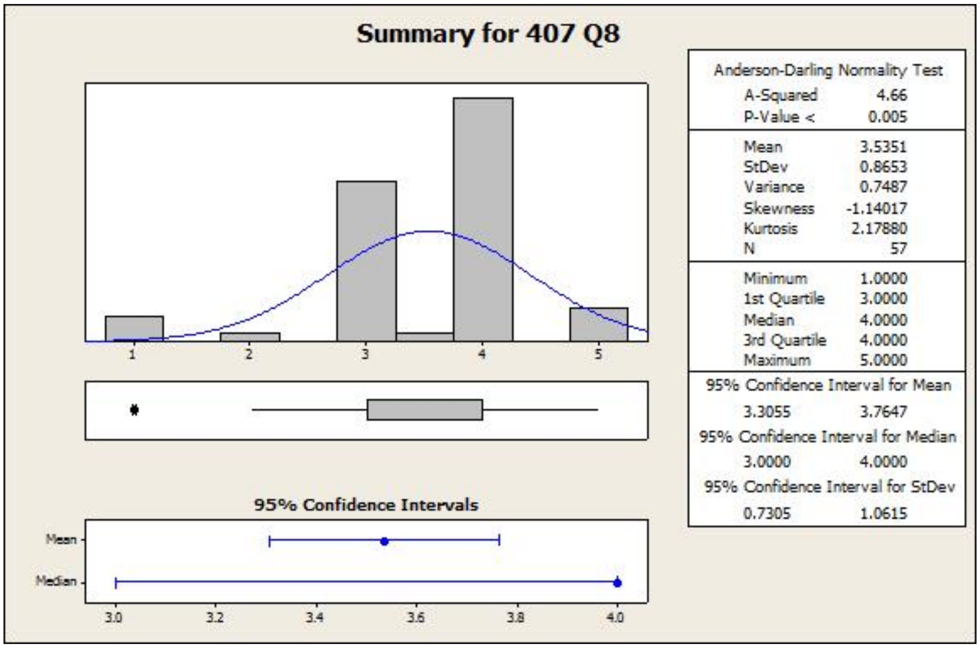

**FigureF15: Basic Statistical Summary of Question5 According to ENDG 407 Students**



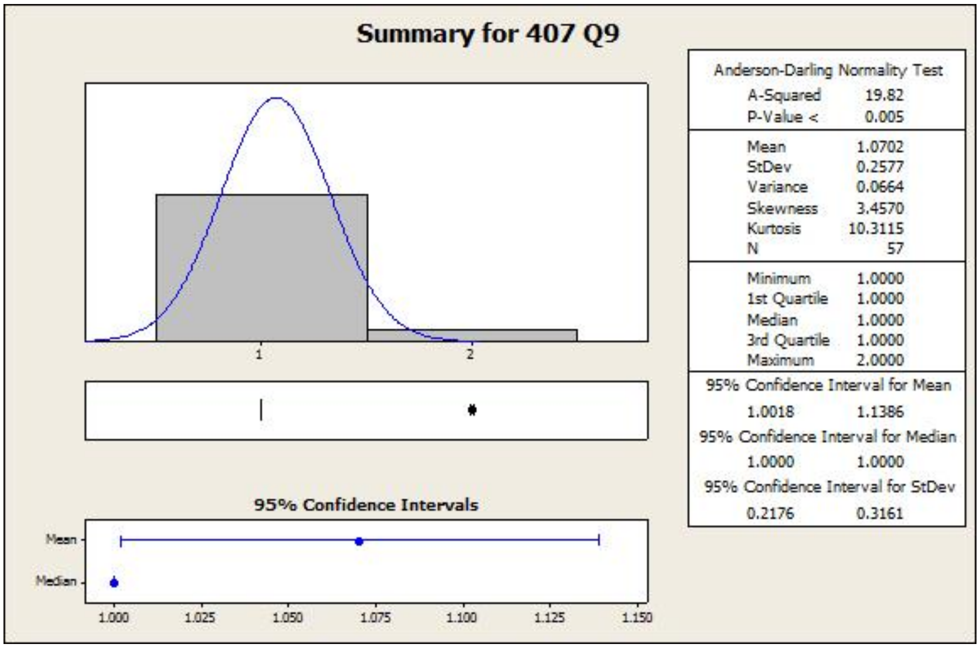

**FigureF16: Basic Statistical Summary of Question6 According to ENDG 407 Students**



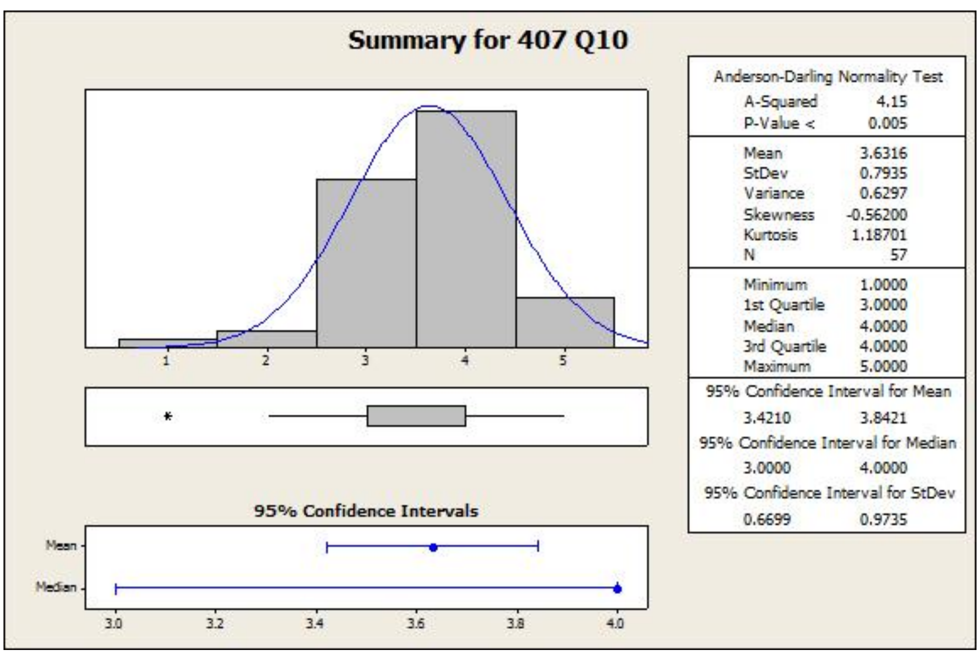

**FigureF17: Basic Statistical Summary of Question7 According to ENDG 407 Students**



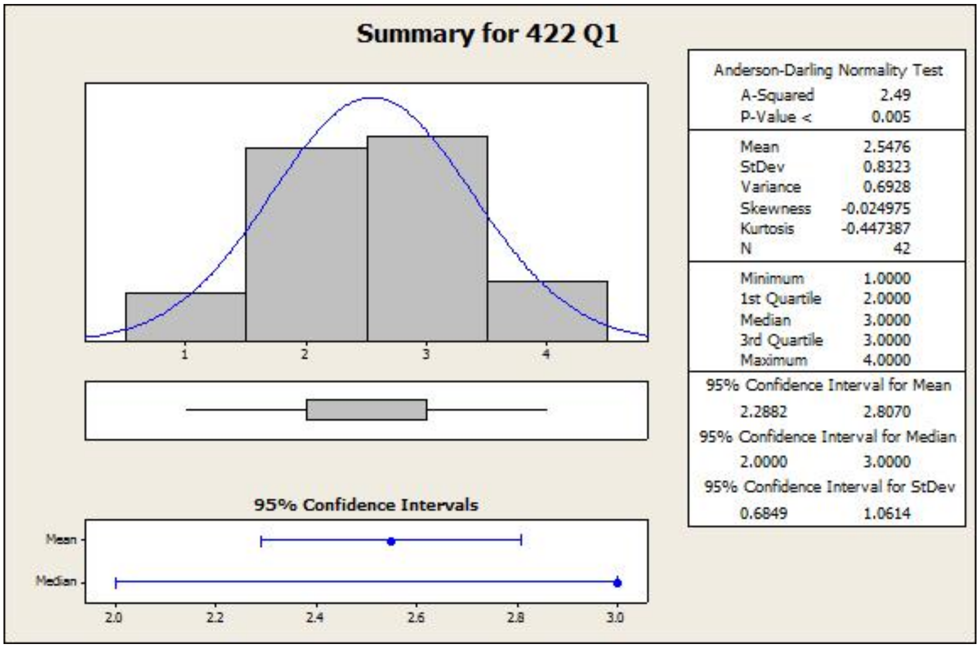

**FigureF18: Basic Statistical Summary of Question8 According to ENDG 407 Students**



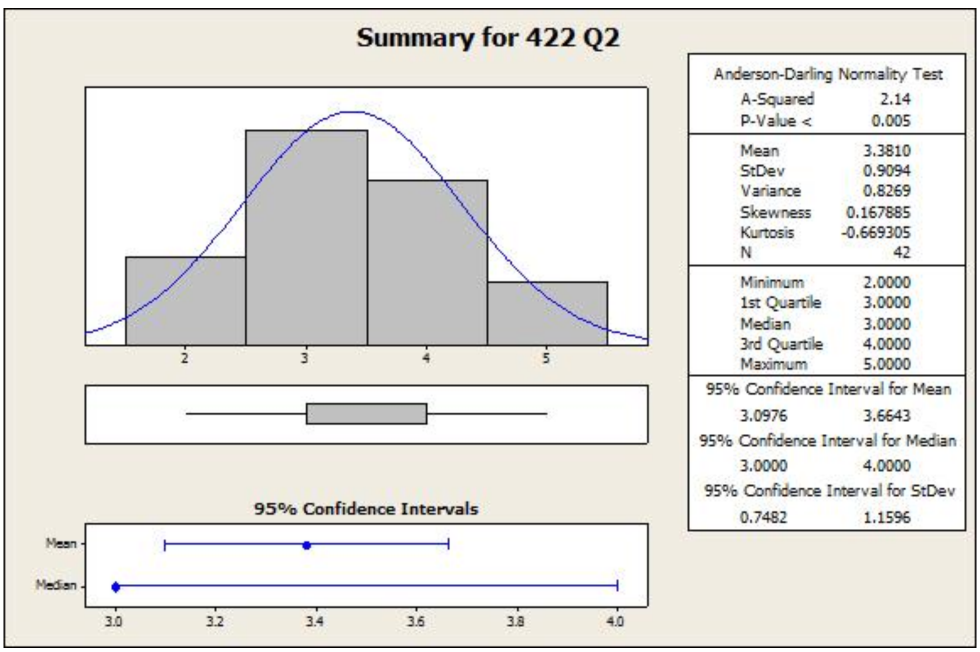

**FigureF19: Basic Statistical Summary of Question9 According to ENDG 407 Students**



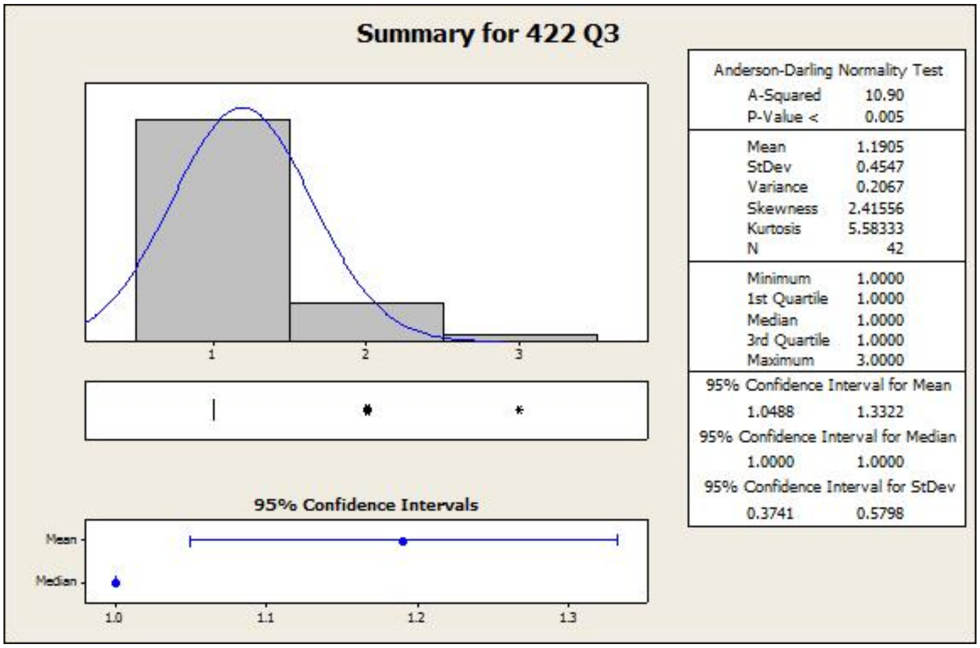

**FigureF20: Basic Statistical Summary of Question10 According to ENDG 407 Students**



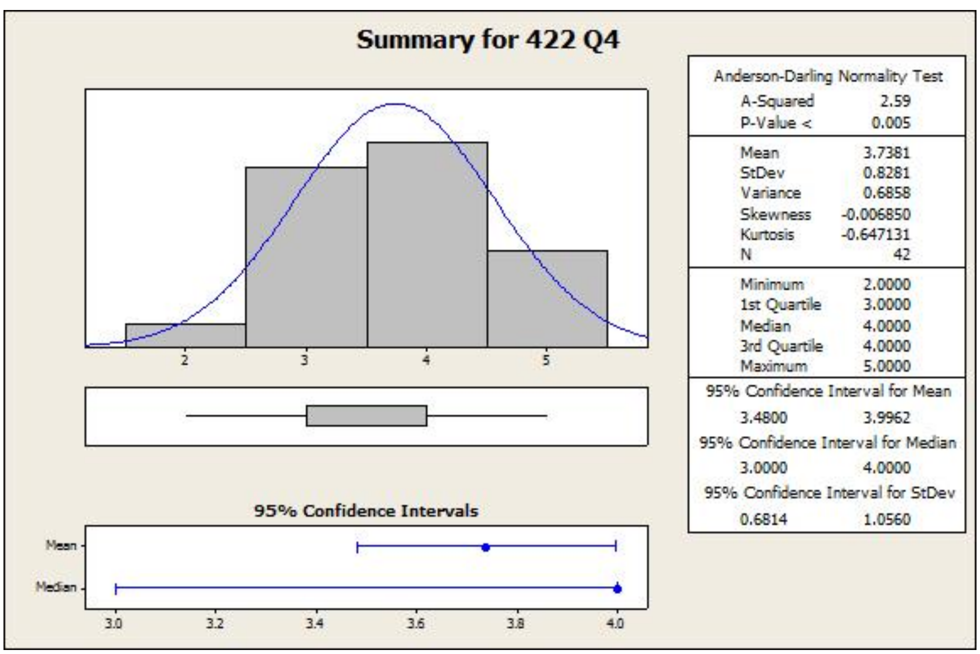

**FigureF21: Basic Statistical Summary of Question1 According to ENTC 422 Students**



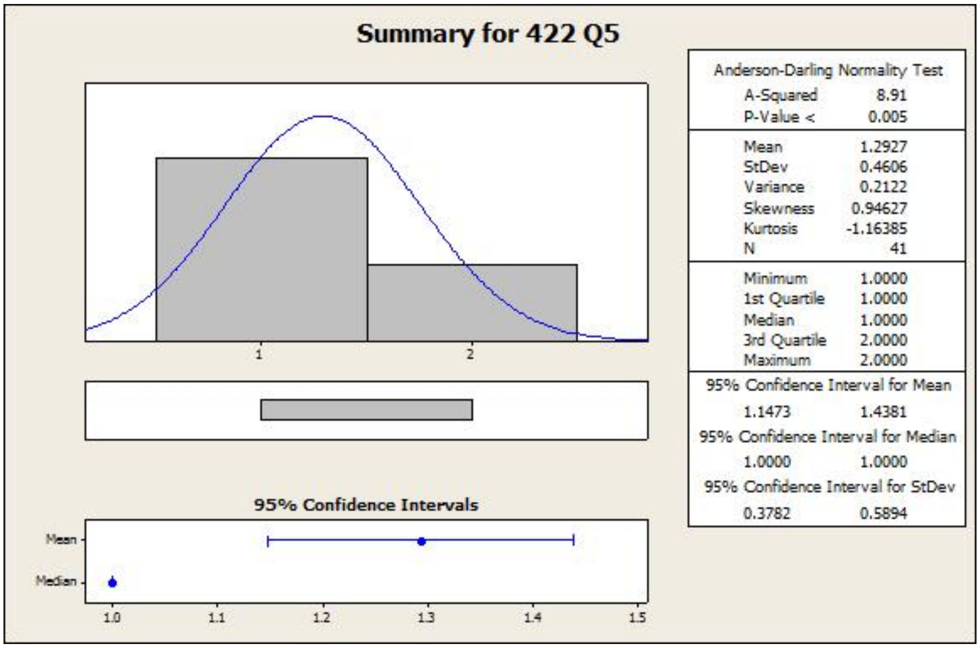

**FigureF22: Basic Statistical Summary of Question2 According to ENTC 422 Students**



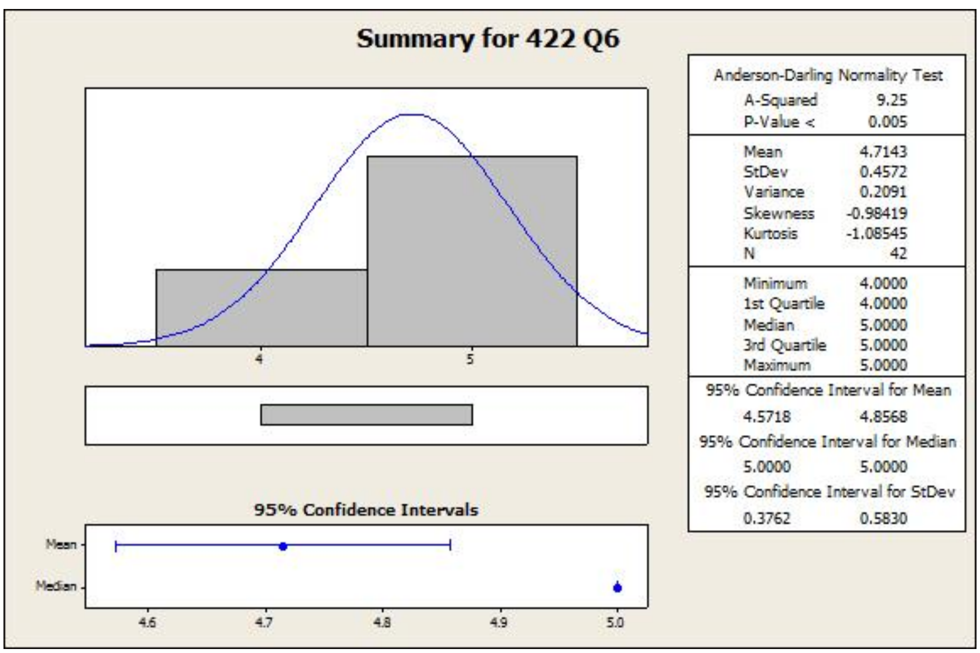

**FigureF23: Basic Statistical Summary of Question3 According to ENTC 422 Students**



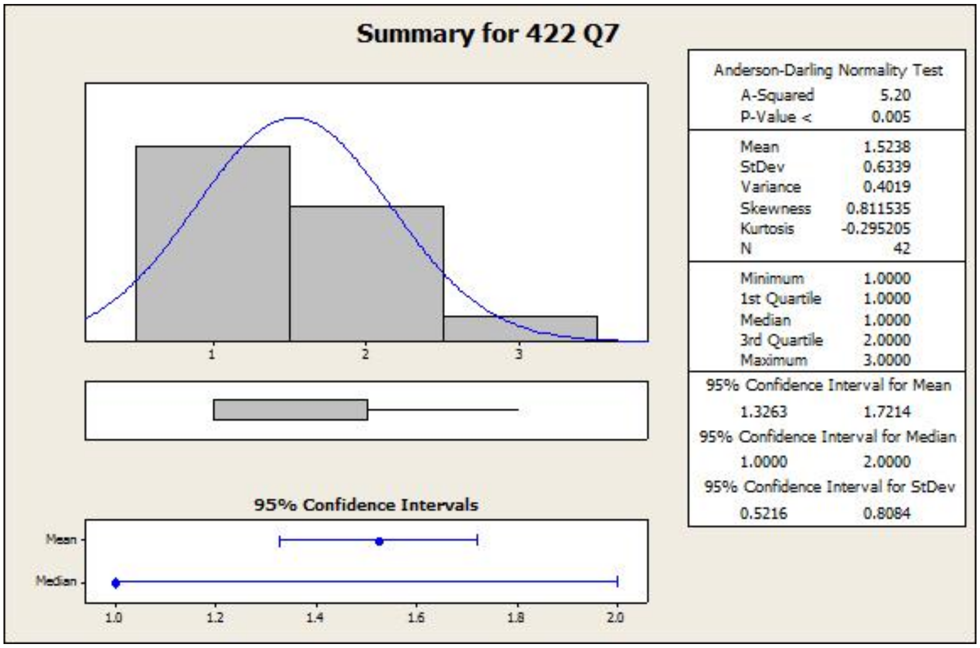

**FigureF24: Basic Statistical Summary of Question4 According to ENTC 422 Students**



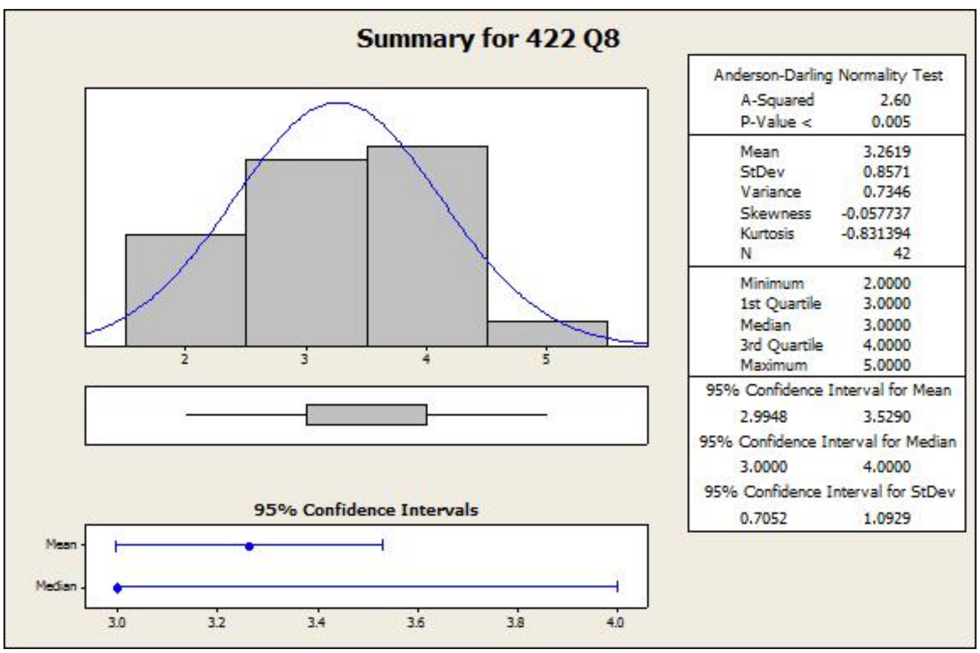

**FigureF25: Basic Statistical Summary of Question5 According to ENTC 422 Students**



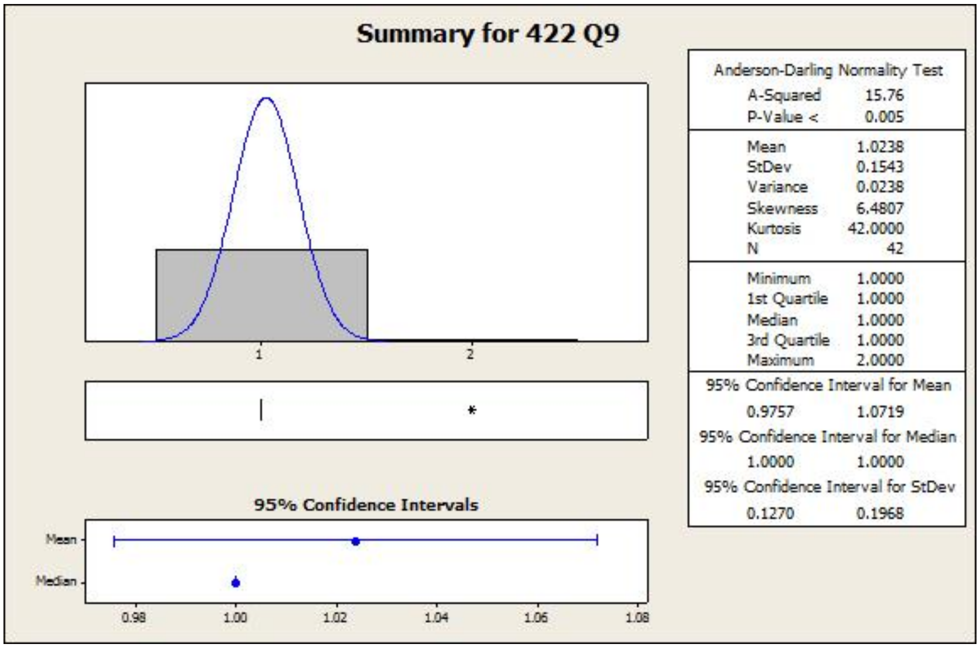

**FigureF26: Basic Statistical Summary of Question6 According to ENTC 422 Students**



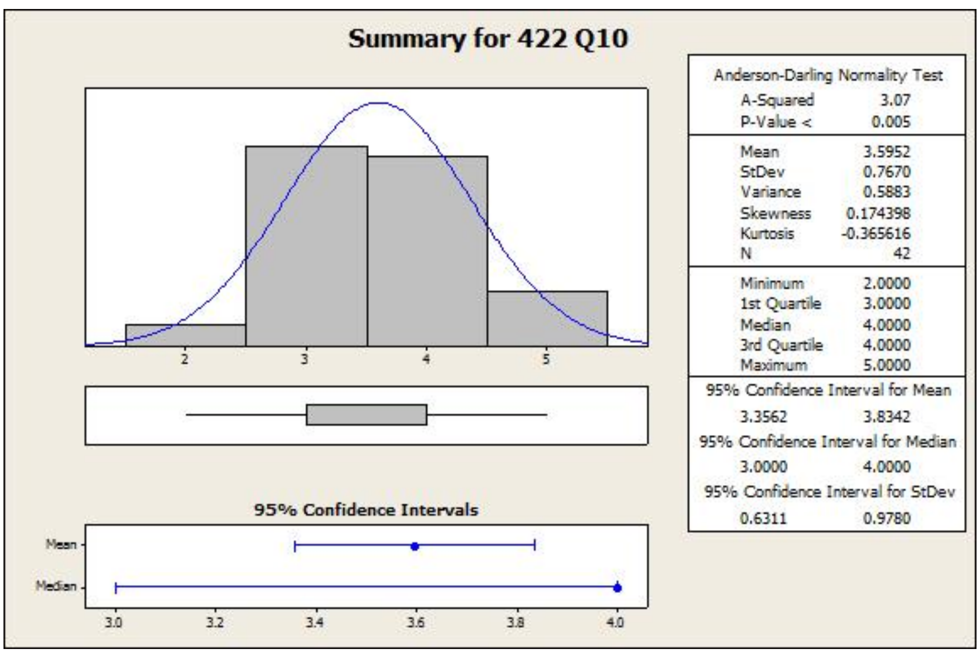

**FigureF27: Basic Statistical Summary of Question7 According to ENTC 422 Students**




**FigureF28: Basic Statistical Summary of Question8 According to ENTC 422 Students**




**FigureF29: Basic Statistical Summary of Question9 According to ENTC 422 Students**




**FigureF30: Basic Statistical Summary of Question10 According to ENTC 422 Students**

# APPENDIX G: T-Test Statistical Analysis Results

## Two-Sample T-Test and CI: 422 Q1, 407 Q1

```
Two-sample T for 422 Q1 vs 407 Q1

         N   Mean  StDev  SE Mean
422 Q1  42  2.548  0.832     0.13
407 Q1  57  2.491  0.826     0.11


Difference = mu (422 Q1) - mu (407 Q1)
Estimate for difference:  0.056
95% CI for difference:  (-0.279, 0.392)
T-Test of difference = 0 (vs not =): T-Value = 0.33  P-Value = 0.739  DF = 88
```

## Two-Sample T-Test and CI: 422 Q2, 407 Q2

```
Two-sample T for 422 Q2 vs 407 Q2

         N   Mean  StDev  SE Mean
422 Q2  42  3.381  0.909     0.14
407 Q2  57  3.088  0.931     0.12


Difference = mu (422 Q2) - mu (407 Q2)
Estimate for difference:  0.293
95% CI for difference:  (-0.078, 0.664)
T-Test of difference = 0 (vs not =): T-Value = 1.57  P-Value = 0.120  DF = 89
```

## Two-Sample T-Test and CI: 422 Q3, 407 Q3

```
Two-sample T for 422 Q3 vs 407 Q3

         N   Mean  StDev  SE Mean
422 Q3  42  1.190  0.455    0.070
407 Q3  57  1.298  0.706    0.094


Difference = mu (422 Q3) - mu (407 Q3)
Estimate for difference:  -0.108
95% CI for difference:  (-0.340, 0.124)
T-Test of difference = 0 (vs not =): T-Value = -0.92  P-Value = 0.359  DF = 95
```

## Two-Sample T-Test and CI: 422 Q4, 407 Q4

```
Two-sample T for 422 Q4 vs 407 Q4

         N   Mean  StDev  SE Mean
422 Q4  42  3.738  0.828     0.13
407 Q4  57  3.632  0.816     0.11


Difference = mu (422 Q4) - mu (407 Q4)
Estimate for difference:  0.107
95% CI for difference:  (-0.226, 0.439)
T-Test of difference = 0 (vs not =): T-Value = 0.64  P-Value = 0.526  DF = 87
```

## Two-Sample T-Test and CI: 422 Q5, 407 Q5

```
Two-sample T for 422 Q5 vs 407 Q5

         N   Mean  StDev  SE Mean
422 Q5  41  1.293  0.461    0.072
407 Q5  57  1.544  0.629    0.083


Difference = mu (422 Q5) - mu (407 Q5)
Estimate for difference:  -0.251
95% CI for difference:  (-0.470, -0.033)
T-Test of difference = 0 (vs not =): T-Value = -2.28  P-Value = 0.025  DF = 95
```

## Two-Sample T-Test and CI: 422 Q6, 407 Q6

```
Two-sample T for 422 Q6 vs 407 Q6

         N   Mean  StDev  SE Mean
422 Q6  42  4.714  0.457    0.071
407 Q6  57  4.719  0.526    0.070


Difference = mu (422 Q6) - mu (407 Q6)
Estimate for difference:  -0.0050
95% CI for difference:  (-0.2019, 0.1919)
T-Test of difference = 0 (vs not =): T-Value = -0.05  P-Value = 0.960  DF = 94
```

## Two-Sample T-Test and CI: 422 Q7, 407 Q7

```
Two-sample T for 422 Q7 vs 407 Q7

         N   Mean  StDev  SE Mean
422 Q7  42  1.524  0.634    0.098
407 Q7  57  1.684  0.659    0.087


Difference = mu (422 Q7) - mu (407 Q7)
Estimate for difference:  -0.160
95% CI for difference:  (-0.421, 0.100)
T-Test of difference = 0 (vs not =): T-Value = -1.22  P-Value = 0.224  DF = 90
```

## Two-Sample T-Test and CI: 422 Q8, 407 Q8

```
Two-sample T for 422 Q8 vs 407 Q8

         N   Mean  StDev  SE Mean
422 Q8  42  3.262  0.857     0.13
407 Q8  57  3.535  0.865     0.11


Difference = mu (422 Q8) - mu (407 Q8)
Estimate for difference:  -0.273
95% CI for difference:  (-0.621, 0.075)
T-Test of difference = 0 (vs not =): T-Value = -1.56  P-Value = 0.122  DF = 88
```

### Two-Sample T-Test and CI: 422 Q9, 407 Q9

```
Two-sample T for 422 Q9 vs 407 Q9

         N   Mean  StDev  SE Mean
422 Q9  42  1.024  0.154    0.024
407 Q9  57  1.070  0.258    0.034


Difference = mu (422 Q9) - mu (407 Q9)
Estimate for difference:  -0.0464
95% CI for difference:  (-0.1290, 0.0363)
T-Test of difference = 0 (vs not =): T-Value = -1.11  P-Value = 0.268  DF = 93
```

### Two-Sample T-Test and CI: 422 Q10, 407 Q10

```
Two-sample T for 422 Q10 vs 407 Q10

          N   Mean  StDev  SE Mean
422 Q10  42  3.595  0.767     0.12
407 Q10  57  3.632  0.794     0.11


Difference = mu (422 Q10) - mu (407 Q10)
Estimate for difference:  -0.036
95% CI for difference:  (-0.351, 0.278)
T-Test of difference = 0 (vs not =): T-Value = -0.23  P-Value = 0.819  DF = 90
```

### Two-Sample T-Test and CI: 422 Q1, 105 Q1

```
Two-sample T for 422 Q1 vs 105 Q1

         N   Mean  StDev  SE Mean
422 Q1  42  2.548  0.832     0.13
105 Q1  70  3.486  0.847     0.10


Difference = mu (422 Q1) - mu (105 Q1)
Estimate for difference:  -0.938
95% CI for difference:  (-1.263, -0.613)
T-Test of difference = 0 (vs not =): T-Value = -5.74  P-Value = 0.000  DF = 87
```

### Two-Sample T-Test and CI: 422 Q2, 105 Q2

```
Two-sample T for 422 Q2 vs 105 Q2

         N   Mean  StDev  SE Mean
422 Q2  42  3.381  0.909     0.14
105 Q2  70  3.786  0.815    0.097


Difference = mu (422 Q2) - mu (105 Q2)
Estimate for difference:  -0.405
95% CI for difference:  (-0.745, -0.065)
T-Test of difference = 0 (vs not =): T-Value = -2.37  P-Value = 0.020  DF = 79
```

## Two-Sample T-Test and CI: 422 Q3, 105 Q3

```
Two-sample T for 422 Q3 vs 105 Q3

         N   Mean  StDev  SE Mean
422 Q3  42  1.190  0.455    0.070
105 Q3  69   1.59   1.02     0.12


Difference = mu (422 Q3) - mu (105 Q3)
Estimate for difference:  -0.404
95% CI for difference:  (-0.684, -0.123)
T-Test of difference = 0 (vs not =): T-Value = -2.86  P-Value = 0.005  DF = 101
```

## Two-Sample T-Test and CI: 422 Q4, 105 Q4

```
Two-sample T for 422 Q4 vs 105 Q4

         N   Mean  StDev  SE Mean
422 Q4  42  3.738  0.828     0.13
105 Q4  70  3.986  0.843     0.10


Difference = mu (422 Q4) - mu (105 Q4)
Estimate for difference:  -0.248
95% CI for difference:  (-0.571, 0.076)
T-Test of difference = 0 (vs not =): T-Value = -1.52  P-Value = 0.132  DF = 87
```

## Two-Sample T-Test and CI: 422 Q5, 105 Q5

```
Two-sample T for 422 Q5 vs 105 Q5

         N   Mean  StDev  SE Mean
422 Q5  41  1.293  0.461    0.072
105 Q5  69  1.812  0.670    0.081


Difference = mu (422 Q5) - mu (105 Q5)
Estimate for difference:  -0.519
95% CI for difference:  (-0.733, -0.305)
T-Test of difference = 0 (vs not =): T-Value = -4.80  P-Value = 0.000  DF = 105
```

## Two-Sample T-Test and CI: 422 Q6, 105 Q6

```
Two-sample T for 422 Q6 vs 105 Q6

         N   Mean  StDev  SE Mean
422 Q6  42  4.714  0.457    0.071
105 Q6  70  4.914  0.282    0.034


Difference = mu (422 Q6) - mu (105 Q6)
Estimate for difference:  -0.2000
95% CI for difference:  (-0.3565, -0.0435)
T-Test of difference = 0 (vs not =): T-Value = -2.56  P-Value = 0.013  DF = 59
```

## Two-Sample T-Test and CI: 422 Q7, 105 Q7

```
Two-sample T for 422 Q7 vs 105 Q7

         N   Mean  StDev  SE Mean
422 Q7  42  1.524  0.634    0.098
105 Q7  70  2.143  0.708    0.085


Difference = mu (422 Q7) - mu (105 Q7)
Estimate for difference:  -0.619
95% CI for difference:  (-0.876, -0.362)
T-Test of difference = 0 (vs not =): T-Value = -4.79  P-Value = 0.000  DF = 94
```

## Two-Sample T-Test and CI: 422 Q8, 105 Q8

```
Two-sample T for 422 Q8 vs 105 Q8

         N   Mean  StDev  SE Mean
422 Q8  42  3.262  0.857     0.13
105 Q8  70  3.993  0.754    0.090


Difference = mu (422 Q8) - mu (105 Q8)
Estimate for difference:  -0.731
95% CI for difference:  (-1.050, -0.412)
T-Test of difference = 0 (vs not =): T-Value = -4.57  P-Value = 0.000  DF = 77
```

## Two-Sample T-Test and CI: 422 Q9, 105 Q9

```
Two-sample T for 422 Q9 vs 105 Q9

         N   Mean  StDev  SE Mean
422 Q9  42  1.024  0.154    0.024
105 Q9  70  1.229  0.456    0.054


Difference = mu (422 Q9) - mu (105 Q9)
Estimate for difference:  -0.2048
95% CI for difference:  (-0.3229, -0.0867)
T-Test of difference = 0 (vs not =): T-Value = -3.44  P-Value = 0.001  DF = 92
```

## Two-Sample T-Test and CI: 422 Q10, 105 Q10

```
Two-sample T for 422 Q10 vs 105 Q10

          N   Mean  StDev  SE Mean
422 Q10  42  3.595  0.767     0.12
105 Q10  70  3.886  0.790    0.094


Difference = mu (422 Q10) - mu (105 Q10)
Estimate for difference:  -0.290
95% CI for difference:  (-0.591, 0.010)
T-Test of difference = 0 (vs not =): T-Value = -1.92  P-Value = 0.058  DF = 88
```

# APPENDIX H: Spearman's Rho Statistical Analysis Results

### Correlations: Rank Order for All Students, Rank Order Part Volume Ratio

```
Pearson correlation of Rank Order for All Students and Rank Order Part Volume
     Ratio = 0.927
```

### Correlations: Rank Order for All Students, Rank by Cube Ratio

```
Pearson correlation of Rank Order for All Students and Rank by Cube Ratio =
     -0.770
```

### Correlations: Rank Order for All Students, Rank by Sphere Ratio

```
Pearson correlation of Rank Order for All Students and Rank by Sphere Ratio =
     -0.770
```

### Correlations: rank 105, Rank Order Part Volume Ratio

```
Pearson correlation of rank 105 and Rank Order Part Volume Ratio = 0.891
```

### Correlations: rank 407, Rank Order Part Volume Ratio

```
Pearson correlation of rank 407 and Rank Order Part Volume Ratio = 0.936
```

### Correlations: rank 422, Rank Order Part Volume Ratio

```
Pearson correlation of rank 422 and Rank Order Part Volume Ratio = 0.903
```

### Correlations: Rank of advanced students, Rank Order Part Volume Ratio

```
Pearson correlation of Rank of advanced students and Rank Order Part Volume
     Ratio = -0.830
```

### Correlations: Rank by Cube Ratio, rank 105

```
Pearson correlation of Rank by Cube Ratio and rank 105 = -0.818
```

### Correlations: Rank by Cube Ratio, rank 407

```
Pearson correlation of Rank by Cube Ratio and rank 407 = -0.736
```

### Correlations: Rank by Cube Ratio, rank 422

```
Pearson correlation of Rank by Cube Ratio and rank 422 = -0.733
```

### Correlations: Rank by Cube Ratio, Rank of advanced students

```
Pearson correlation of Rank by Cube Ratio and Rank of advanced students = 0.273
```

### Correlations: Rank by Sphere Ratio, rank 105

```
Pearson correlation of Rank by Sphere Ratio and rank 105 = -0.818
```

### Correlations: Rank by Sphere Ratio, rank 407

```
Pearson correlation of Rank by Sphere Ratio and rank 407 = -0.736
```

### Correlations: Rank by Sphere Ratio, rank 422

```
Pearson correlation of Rank by Sphere Ratio and rank 422 = -0.733
```

### Correlations: Rank by Sphere Ratio, Rank of advanced students

```
Pearson correlation of Rank by Sphere Ratio and Rank of advanced students =
     0.273
```

### Correlations: rank 105, rank 422

```
Pearson correlation of rank 105 and rank 422 = 0.927
```

### Correlations: rank 407, rank 422

```
Pearson correlation of rank 407 and rank 422 = 0.985
```

### Correlations: rank 105, Rank of advanced students

```
Pearson correlation of rank 105 and Rank of advanced students = -0.697
```