



## **Undergraduate STEM Students' Role in Making Technology Decisions for Solving Calculus Questions and the Impact of These Decisions on Learning Calculus**

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Emre Tokgoz is currently the Director and an Assistant Professor of Industrial Engineering at Quinnipiac University. He completed a Ph.D. in Mathematics and another Ph.D. in Industrial and Systems Engineering at the University of Oklahoma. His pedagogical research interest includes technology and calculus education of STEM majors. He worked on several IRB approved pedagogical studies to observe undergraduate and graduate mathematics and engineering students' calculus and technology knowledge since 2011. His other research interests include nonlinear optimization, financial engineering, facility allocation problem, vehicle routing problem, solar energy systems, machine learning, system design, network analysis, inventory systems, and Riemannian geometry.

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My name is Elif Naz Tekalp. I am a junior industrial engineering student at Quinnipiac University. I also have mathematics and general business minor. I am interested in the role of mathematics in engineering education and professional life. I was very passionate about the research that I participated with my Dr. Emre Tokgoz.

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My name is Berrak Seren Tekalp, I am from Turkey, and I am a junior in Industrial Engineering at Quinnipiac University. I have a mathematics and a general business minor. Beginning in my sophomore year, I've done many academic types of research with my professors. In these projects, I have used advanced features within the IBM SPSS Statistics and Excel programs. I am a hard and reliable worker. I have been able to expand my communication skills, and through my time as an active member of multiple student organizations and engineering groups at Quinnipiac. I've led numerous meetings and club projects. I am comfortable with working in teams.

# Undergraduate STEM Students' Role in Making Technology Decisions for Solving Calculus Questions and the Impact of These Decisions on Learning Calculus

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## 1. Introduction

There are challenging problems in STEM research that can be solved by using different technologies. STEM students are usually expected to have a good grasp of the paper-pencil solution to calculus questions to demonstrate critical thinking ability while they are also expected to use technology to determine solutions to these questions. The strategic use of technology by STEM majors enhances their engineering and mathematics learning. Technology education of students for making right decisions to pick the right technology for solving calculus questions is a crucial component of calculus education. There are many challenging problems that might require the use of one of the following technologies:

- Computer programming languages: Matlab, Excel, etc.
- Calculators: Texas Instruments 83, 83+, 84, 86, 89, 89-Titanium, etc.
- Online resources: Wolfram Alpha, Symbolab, Desmos, etc.

The research results shared in this work received IRB approval for data collection. Qualitative and Quantitative data were collected during the research period. The goal of the following question was to investigate participating students' technology choice to graph a given function.

If you are required to draw the graph of a given function by using technology, what kind of technology would you use? Please either choose one of the following or write your own answer and explain why.

1. Calculator (If this is your choice please specify the kind of calculator you use)

2. Excel

3. C

4. C++

5. C#

6. Fortran

7. MATLAB

8. LabVIEW

9. Other \_\_\_\_\_

The goal of the question below is to investigate whether students would choose to use a technology to calculate a definite integral or prefer to solve a given definite integral by hand. This question was particularly designed to investigate engineering students' interest to use a software or prefer to solve a problem by using the integral techniques they learn in calculus.

If there is a definite integral given, which one of the following would you prefer to use to calculate the given integral? Please circle the option and briefly explain why.

1. Computer Program (which program)
2. Calculator (which calculator)
3. By hand
4. Other (Please type)

If you are required to use a computer program to find the solution of the given definite integral, which computer language would you prefer to use?

A calculus question that might require the use of technology is the calculation of numerical values or error terms for a given power series; The following question targeted determining the participants technology background and knowledge to determine such values.

If you needed to calculate numerical values of power series or error term graphs/values which method (algebraic calculations, computer program (please specify), calculator etc.) would you use? If you are required to pick a computer program what programming language would you prefer to use? Please either choose one of the following or write your own answer and explain why.

1. Calculator (If this is your choice please specify the kind of calculator you use)
2. Excel
3. C
4. C++
5. C#
6. Fortran
7. MATLAB
8. LabVIEW
9. Other \_\_\_\_\_

In this work, the quantitative data analysis consisted of the statistical analysis of the participants' responses to the research questions and the qualitative nature of the data is the transcription of the 20 participants' video recorded interviews at a university located on the Northeastern side of the United States. The focus of this research is different from majority of the other existing research that focuses on the learning preferences of students to solve engineering problems; (see for example Felder and Silverman (1988) and Rosati (1998).) Students' preferences on using paper-pencil versus technology to solve the research questions are also investigated in [Article of one of the authors, year] for improving technology education of STEM students with the impact on their calculus educational experience.

## 2. Nature of the Research & Collected Data

The data collection methodology received Institutional Review Board (IRB) approval prior to the collection of the data. There were two phases of data collection: pre- and post-interview phases. Pre-interview phase required the participants to answer a set of questions in which the three research questions analyzed in this work took place. The post-interview phase consisted of video recorded interviews of the participants to investigate the details of their written responses to the written questionnaire. Each participant got compensated by the lead researcher for participating each one of the two phases of the data collection periods. The data is collected at a Northeastern university in the United States. Twenty undergraduate engineering majors participated in this research completed two of the 4-credit calculus course sequence in a 12-credit calculus sequence.

The lead researcher hired three undergraduate students that participated in the data collection and helped to derive the results attained in this work. Each participant is interviewed approximately 20-30 minutes to further investigate the details of the written responses. The following were the main objectives of the three research questions analyzed in this article:

- Technology preferences of undergraduate engineering students for solving function graphing, definite integral, and mathematical series questions;
- Technology variation of participating engineering students' technology preferences when calculus concepts change. I.e. Do the students prefer a different technology (or not prefer at all) when calculus questions change?
- Engineering students' interest in determining the solution to a calculus problem by using paper and pencil rather than technology;
- The engineering majors' consistency in using the same technology as calculus problems change.

The following are investigated for engineering educators and researchers to benefit from the data displayed in this work:

- Undergraduate engineering students' reasons and believes for choosing various technologies.
- The technological shortcomings that arise in engineering education for solving mathematics problems.
- The limitations of engineering students' technology knowledge.
- Correlation of participants' technology choices for a variety of calculus questions.

Next three sections are organized section-by-section for qualitative and quantitative analysis of participants' technology preferences to the three research questions related to function graphing, solving definite integrals, and calculating power series or error terms. The sixth section is devoted to correlation analysis of participants' technology preferences for the three research questions. The last section presents an overview of the analysis of the results displayed in this work.

### **3. Analysis of Technology Choices for Function Graphing**

Qualitative and quantitative analysis of the research participants' technology choices to solve the function graphing question are presented in this section. Participants' handwritten responses to the research question, interview transcriptions, and statistical analysis are the key elements displayed in this section.

Majority of the participants' responses, 80%, indicated calculators to be the most popular technology choice for graphing a function as displayed in Figure 1 below; Texas Instrument (TI) calculators were the top choice of majority of the participants. The other technologies preferred to be used by the participants included Excel and Matlab. Some of the participants chose web-based graphing calculators (such as the one offered by Desmos.com) as the secondary choice while their primary choice was the use of a calculator.

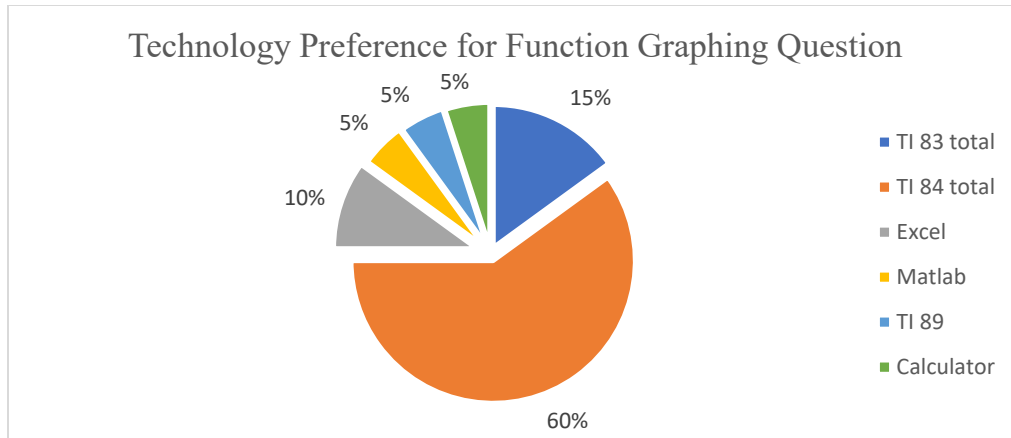


Fig 1. Participants technology preference distribution to graph a function

The primary reason for participants' technology choices for function graphing was "experience" with the calculator during the completion of their university level courses and high school years as indicated by one of such participants below in Figure 2.

5. If you are required to draw the graph of a given function by using technology, what kind of technology would you use? Please either choose one of the following or write your own answer and explain why.

- ① Calculator (If this is your choice please specify the kind of calculator you use)
2. Excel
3. C
4. C++
5. C#
6. Fortran
7. MATLAB
8. LabVIEW
9. Other -----

TI-84 + calculator, because I have more experience graphing on my calculator than excel and have never graphed on a programming language before.

Fig 2. Experience based technology preference of Participant 5 for choosing graphing calculator

The following participant, Participant 8, in Figure 3 had a conditional choice to graph a function. The response was based on points to plot versus a function given in a closed form with the corresponding variable.

5. If you are required to draw the graph of a given function by using technology, what kind of technology would you use? Please either choose one of the following or write your own answer and explain why.

- ① Calculator (If this is your choice please specify the kind of calculator you use)
- ② Excel
3. C
4. C++
5. C#
6. Fortran
7. MATLAB
8. LabVIEW
9. Other -----

I would use a calculator if given a function of  $x$  (TI-83 Plus) and I would use excel if I was given points to plot

Fig 3. Preference based response of Participant 8 to sketch the graph of a function

The following participant, Participant 9, preferred to use Desmos graphing calculator to sketch the graph of a function over the TI-84 calculator “to ensure a more reliable answer.”

5. If you are required to draw the graph of a given function by using technology, what kind of technology would you use? Please either choose one of the following or write your own answer and explain why.

1. Calculator (If this is your choice please specify the kind of calculator you use)
2. Excel
3. C
4. C++
5. C#
6. Fortran
7. MATLAB
8. LabVIEW
9. Other \_\_\_\_\_

I would use my TI-84 calculator or Desmos graphing calculator from the internet. would prefer Desmos to ensure a more reliable answer.

Fig 4. Reliability based response of Participant 9.

Excel and Matlab were chosen by few participants for this question. The reason for choosing this option, as stated by Participant 16 below, was based on the “familiarity” even though the graphing of a function is Excel is not as simple as some of the online resources such as the graphing calculator offered by Desmos.com.

5. If you are required to draw the graph of a given function by using technology, what kind of technology would you use? Please either choose one of the following or write your own answer and explain why.

1. Calculator (If this is your choice please specify the kind of calculator you use)
2. Excel
3. C
4. C++
5. C#
6. Fortran
7. MATLAB
8. LabVIEW
9. Other \_\_\_\_\_

most familiar with excel and graphing

Fig 5. Participant 16 chose Excel because of “most familiarity” with Excel to graph a function.

In a nutshell, the participants technology choices were based on the following categories for graphing a function:

- Experience with the technology.
- Preference.
- Reliability.
- Familiarity.

Some of the participants with multiple technology preferences for graphing a function clearly indicated a certain knowledge on knowing how to use these technologies. All the responses of the participants were based on the idea “I am familiar and know how to solve it.”

#### 4. Technology Choice Analysis of Engineering Majors for Calculating Integrals

The research participants' choices to solve the integral approximation question will be analyzed qualitatively and quantitatively in this section. Participants' handwritten and interview responses to the research question and statistical analysis were the key elements of the analysis. Figure 5 below outlines the percentage distribution of the research participants' preferences to solve an integral question. The most interesting result is half of the engineering majors preferring to solve a definite integral by hand rather than using a technology. This is a consequence of participants' calculus course education without using a software. This fact appears to overrule the technology preference of the participants to solve definite integrals even though most of them learned several technologies to solve definite integrals.

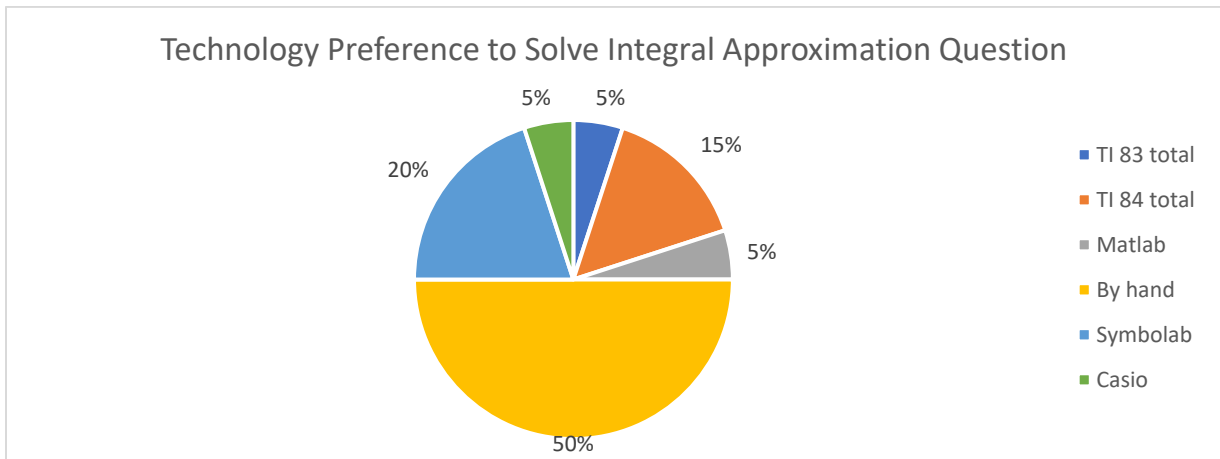


Fig 5. Statistics on participants technology preferences to calculate integral approximation

Several examples of participant responses are displayed below to show their preferences. Response of Participant 5 in Figure 6 was based on “the training” method to solve definite integrals; the participant didn't consider using Matlab to solve the problem even though the participant learned how to program Matlab in the past to an extent.

9. If there is a definite integral given, which one of the following would you prefer to use to calculate the given integral? Please circle the option and briefly explain why.

1. Computer Program (which program)

② Calculator (which calculator) TI-84+, combination of calculator

③ By hand and by hand since this is the way I learned

4. Other (Please type) and practiced solving definite integrals.

If you are required to use a computer program to find the solution of the given definite integral, which computer language would you prefer to use?

I don't know how to solve a definite integral using any computer program.

Fig 6. Participant 5 chooses to use a combination of a calculator and by hand to solve an integral.

Response of Participant 16 displayed in Figure 7 is based on the “step-by-step” calculation capability of Symbolab.com that is chosen by 20% of the participants. This website is particularly helpful to view the theoretical method applied to calculate the integral along with the details of the algebraic steps taken to calculate the integral.

9. If there is a definite integral given, which one of the following would you prefer to use to calculate the given integral? Please circle the option and briefly explain why.

1.  Computer Program (which program) *Symbolab*
2.  Calculator (which calculator)
3.  By hand
4.  Other (Please type)

If you are required to use a computer program to find the solution of the given definite integral, which computer language would you prefer to use?

*gives steps on how they solved problem*

Fig 7. Participant 16 chooses Symbolab to calculate definite integrals.

Participant 17 chooses Matlab due to its’ “calculation capabilities” in Figure 8 and user interface (i.e. basic input screen) which is one of the rare options chosen to calculate a definite integral among the research participants.

9. If there is a definite integral given, which one of the following would you prefer to use to calculate the given integral? Please circle the option and briefly explain why.

1.  Computer Program (which program)
2.  Calculator (which calculator)
3.  By hand
4.  Other (Please type)

If you are required to use a computer program to find the solution of the given definite integral, which computer language would you prefer to use?

*I would choose Matlab because of its fast calculation capabilities and basic input screen.*

Fig 8. Participant 17 chooses to use Matlab to solve definite integrals.

Participant 19 (in Figure 9) chose to use a calculator program and “by hand” solution to calculate definite integrals which depends on the “ease of integration of the function.”

9. If there is a definite integral given, which one of the following would you prefer to use to calculate the given integral? Please circle the option and briefly explain why.

1.  Computer Program (which program)
2.  Calculator (which calculator) → *I would use the Euler's 2 programme to calculate it*
3.  By hand → *if it is an easy integral with a small numbers.*
4.  Other (Please type)

If you are required to use a computer program to find the solution of the given definite integral, which computer language would you prefer to use?

*Matlab*

Fig 9. Participant 19 chooses a combination of calculator, by hand and Matlab to determine definite integral.



The participants' technology choices were based on the following categories for calculating definite integrals:

- Experience with the technology.
- Fast calculation.
- Ease of integral calculation.
- Step-by-step calculation display capability.
- Preference.
- Familiarity.

Some of the participants with multiple technology preferences for graphing a function clearly indicated a certain knowledge on knowing how to use these technologies. All the responses of the participants were based on the idea "I am familiar and know how to solve it." For instance, some of the participants chose to use Excel to graph a function even though Excel does not provide a single step solution to graph a function.

### 5. Analysis of Participants' Technology Choices for Power Series Calculations

Technology choices of research participants to calculate power series terms or error values are analyzed in this section qualitatively and quantitatively. Participants' handwritten responses to the research question and statistical analysis are the key elements displayed in this section.

Calculator is the most popular choice (by 65% of the participants) to calculate error terms or power series of functions. Figure 10 below summarizes the percentage distribution of the participants to solve the research question. The second popular choice appeared to be the use of Excel.

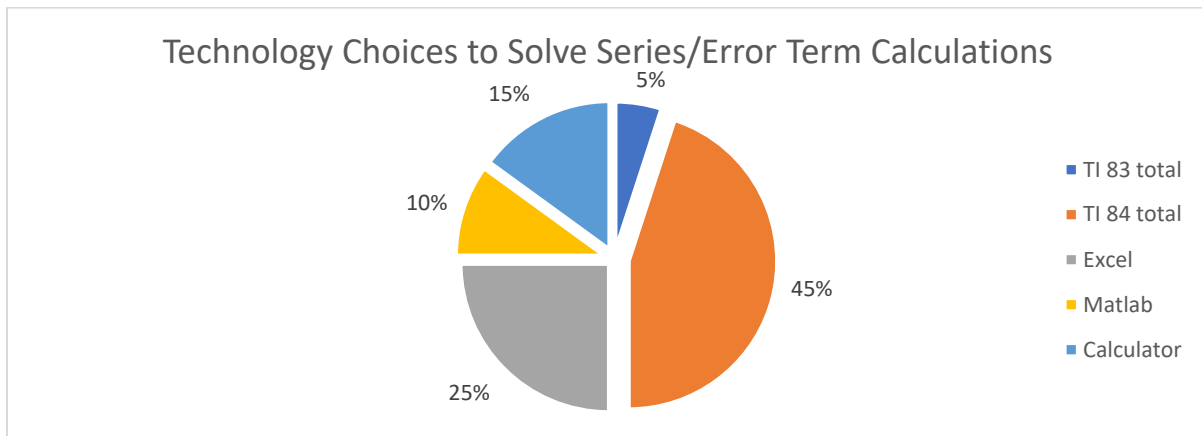


Fig 10. Probability distribution of participants' responses to solve series/error terms

Participant 6 with the response displayed in Figure 11 below chose to use Excel based on the "most familiarity" with the program. This participant didn't know how to calculate the numerical values by using Excel.

11. If you needed to calculate numerical values of power series or error term graphs/values which method (algebraic calculations, computer program (please specify), calculator etc.) would you use? If you are required to pick a computer program what programming language would you prefer to use? Please either choose one of the following or write your own answer and explain why.

1. Calculator (If this is your choice please specify the kind of calculator you use)

- 2. Excel
- 3. C
- 4. C++
- 5. C#
- 6. Fortran
- 7. MATLAB
- 8. LabVIEW
- 9. Other -----

*I do not know any computer programming language. But if I had to choose I am most familiar with Excel.*

Fig 11. Familiarity based response of Participant 6 to the numerical value calculations.

Responses of Participants 12 and 13 displayed in Figures 12 and 13 are based on the availability of shortcuts in Excel and calculators.

11. If you needed to calculate numerical values of power series or error term graphs/values which method (algebraic calculations, computer program (please specify), calculator etc.) would you use? If you are required to pick a computer program what programming language would you prefer to use? Please either choose one of the following or write your own answer and explain why.

1. Calculator (If this is your choice please specify the kind of calculator you use)

- 2. Excel
- 3. C
- 4. C++
- 5. C#
- 6. Fortran
- 7. MATLAB
- 8. LabVIEW
- 9. Other -----

*I'm not sure if excel has functions for this but would be nice*

Fig 12. Response of Participant 12 based on “Function availability” in Excel.

11. If you needed to calculate numerical values of power series or error term graphs/values which method (algebraic calculations, computer program (please specify), calculator etc.) would you use? If you are required to pick a computer program what programming language would you prefer to use? Please either choose one of the following or write your own answer and explain why.

1. Calculator (If this is your choice please specify the kind of calculator you use)

- 2. Excel
- 3. C
- 4. C++
- 5. C#
- 6. Fortran
- 7. MATLAB
- 8. LabVIEW
- 9. Other -----

*Use programs in calculator*

Fig 13. Participant 13 preferred to “use programs in calculator.”

Participant 19 chose Matlab because of its’ “ease of use” as a programming language. The participant didn’t necessarily know how to calculate such numerical values however chose to use the program to solve such problems.

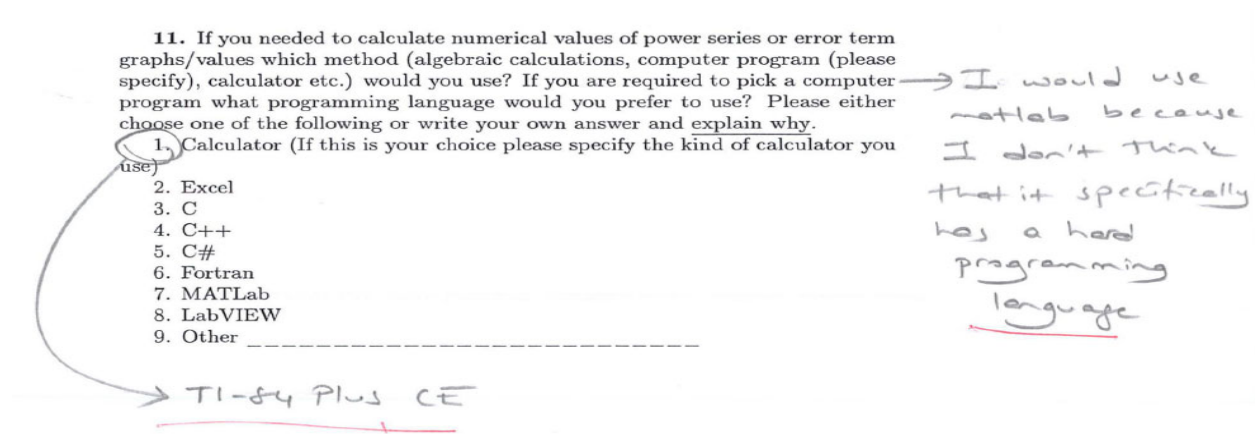


Figure 14. Participant 19 chose Matlab and calculator to calculate numerical values.

Technology choices of the participants were based on the following categories for calculating numerical values of power series or error terms:

- “Function” or “Program” availability.
- Ease of use.
- Preference.
- Familiarity.

Most of the participants chose to use the technology that they are the most familiar with or ease of the use of technology for calculating numerical values of power series or error terms. The responses obtained for this research question was similar to the responses attained for function graphing research question.

## 6. Correlation Analysis of the Research Question Responses

The correlation of the responses to the three technology related questions are analyzed in this section. The purpose of the following correlation analysis was establishing a connection between different questions that are individually analyzed above.

- Only 5% the research participants chose to use the same technology (calculator) to solve all three questions based on the primary choices.
- The highest correlation is determined to be the use of the same technology for Q5 and Q11 with 60% correlation; This meant 60% of the participants preferred to use the same technology to solve these two questions.
- 91.67% of these participants chose to use calculator while 8.33% preferred to use Excel to solve Q5 and Q11.
- Only 5% of the participants correlated to solve Q5 and Q9 by using the same technology, calculator.
- Only 5% of the participants correlated to solve Q9 and Q11 by using the same technology, Matlab.
- If we consider only the participants that chose technology as the second option to solve Q9, 15% of the participants had all three picked to be solved by using a calculator.

- There is a high correlation, 75%, between the participants who preferred to use a calculator for graphing a function and solving the definite integral of a function by hand.
- The participants were mainly inconsistent in their software/program choices for solving the three research questions analyzed in this work.

## 7. Conclusion

The objective of this work was to investigate undergraduate engineering students' technology choices to solve calculus questions related to function graphing, function integral and power series concepts. Pre- and post-interview data were collected from 20 research participants after attaining IRB (Institutional Review Board) approval at a mid-sized Northeastern university in the United States. Research participants were compensated for responding to a written questionnaire and interviewed by the lead researcher to explain their responses more in depth. The main objectives of the three research questions analyzed in this article were to observe the following:

- Technology preferences of undergraduate engineering students for solving function graphing, definite integral, and mathematical series questions;
- Technology variation of participating engineering students' technology preferences when calculus concepts change. i.e. Do the students prefer a different technology (or not prefer at all) when calculus questions change?
- Engineering students' interest in determining the solution to a calculus problem by using paper and pencil rather than technology;
- The engineering majors' consistency in using the same technology as calculus problems change.

In conclusion, the following are the highest statistics observed:

- The highest correlation is determined to be the use of the same technology for Q5 and Q11 with 60% correlation; This meant 60% of the participants preferred to use the same technology to solve these two questions.
- 91.67% of these participants chose to use calculator while 8.33% preferred to use Excel to solve Q5 and Q11.
- Most of the participants, 80%, preferred to use a calculator to sketch the graph of a function.
- 65% of the participants preferred to use a calculator for solving Q11.

Engineering educators and researchers are expected to benefit from the data displayed in this work in several different ways:

- Categorization of participants' technology choices to understand and improve their methods to solve calculus problems.
- An understanding of undergraduate engineering students' cognitive technology preferences for solving calculus questions.
- Recognize the shortcomings that arise in engineering and mathematics education for solving mathematics problems by using technology.
- Recognize the limitations of engineering students' technology knowledge and improve their knowledge accordingly.

The following four common approaches were observed in responses to all three research questions:

- Experience with the technology.
- Preference.
- Reliability.
- Familiarity.

Some of the participants had knowledge in most recent web-based available calculators to calculate definite integrals (Symbolab.com) and function graphs (Desmos.com). Calculator appeared to be the most popular response for solving function graphing (Q5) and power series calculation (Q11) questions while “by hand” was the most popular response to calculate definite integrals. Calculator, Matlab, Excel and web-based resources appeared to be the technology elements that the participants’ preferred for solving the three research questions; Texas Instruments appeared to be the most popular response among all the technologies that can be used to solve the research questions.

Educators and researchers can use the information shared in this work in several different ways. Some of the web-based resources such as Symbolab.com and Desmos.com can be utilized more by the educators to help undergraduate students to improve their technology knowledge. Students can be introduced to use several different technologies in addition to paper pencil solutions. The same technology can be used in different engineering courses for students to build a strong foundation on the corresponding technology to be able to use it for solving different problems in engineering. Several technologies can be taught comprehensively by flipping calculus or engineering courses to incorporate more technologies to solve calculus questions since calculus questions are at the heart of engineering questions. Further investigation by other researchers and educators along the line of this research is essential to learn and improve engineering students’ technology preferences to solve calculus questions.

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Article of one of the authors

Desmos Graphing calculator - <https://www.desmos.com/calculator>

Symbolab - <https://www.symbolab.com/solver/integral-calculator>