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Recent Trends on Technology Choices of STEM Majors for Solving Calculus Questions and Changes Over Years on Relevant Decision Making

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Changes in technology over the years impacted how educational objectives of STEM students' calculus education are fulfilled. Traditional calculus education requires demonstrating paper-pencil solution and critical thinking ability of students. Recent advancements in technology started to impact the ways that educators choose technology for students to use. The educators have been primarily the decision makers for the technologies to be used by the students for learning calculus in the classroom, however it is important to understand students' interest in using technology as decision makers for solving calculus questions. In this work, we analyze the technology choices of 17 and 20 STEM students by using the data collected during 2016 and 2021 years respectively from two different institutions and analyze how technology choices of STEM students changed over these six years. We integrate the analysis of the qualitative and quantitative research data to report the statistical results attained from the three research questions. These research questions are designed to measure the technology choices of STEM students to solve calculus questions that relate to graphing functions, calculating anti-derivatives, and calculating power series expansion of function terms. The comparative results are measured by using correlation analysis and comparative statistics. The quantitative measures indicated strong correlation of the technology choices of students even after 6 years therefore time is observed to not have a strong impact on the technology choices of students.

Keywords: Calculus education, Technology choices, STEM students, Function, Integral, Power Series

1. Introduction

Technology evolved in many different areas of educational settings with advancements in engineering and computing fields. New and recent technologies have further advanced the ways that mathematics can be taught to STEM students for solving challenging calculus problems. Engineering students are typically expected to produce paper-pencil solutions to mathematical problems for instructors to measure their ability to solve questions through mental constructions with additional support of technology to find correct solutions. Educators typically select the technology to be used in a classroom setting that aligns with the course objectives and capabilities of the associated technology. STEM students are expected to learn and use such technology strategically to solve questions. In the case when more than one technology can be used by students within a classroom setting for learning calculus, students often choose a specific technology that may vary with some of the reasonings to be the following:

- Technologies learned during middle or high school years.
- Web-based resources.
- STEM major-specific software packages learned during their existing education.
- Technologies taught by their mathematics instructors.

Some of the technologies that are used extensively for mathematics education included the following [1,2]:

- C++, MatLAB, Excel, etc. (programming languages)
- Texas Instrument (T.I.) calculators such 83, 83+, 84, 86, 89, 89-Titanium, etc. (calculators)
- Wolfram Alpha, Symbolab, Desmos, etc. (web-based resources)

The importance of STEM majors' interest in solving mathematics questions cannot be underestimated as they are the end users of such technologies, and there is limited research on this area of pedagogical research interest to the best of our knowledge. Therefore, we investigate responses to the following research questions to perform both qualitative and quantitative data analysis in this work.

- What technologies would you consider using to draw the graph of a given function?
- Given a definite integral, which technologies would you prefer to use to calculate it?
- To calculate the numerical values of a power series or error term values, which method (algebraic calculations, computer program (please specify), calculator etc.) would you use?

The qualitative nature of the data is the transcription of the participants' video recorded interviews. 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 see [3,4,5,6].) Students' preferences on using technology versus paper-pencil solutions to solve the research questions is investigated for improving technology education of STEM students with the impact on their calculus educational experiences in [1,2]. The following are 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.
- The impact of time on STEM students' technology choices to solve calculus-based questions.
- Variational technology preferences of STEM students when calculusconcepts change. I.e., Do the students prefer 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.

Educators and researchers can benefit from the results of this work in several different ways:

- Undergraduate engineering students' reasons for choosing various technologies.
- The technological shortcomings that arise in engineering education for solving mathematics problems.
- The limitations of engineering students' knowledge of technology.

Research procedures used for the data collection and the nature of the data is explained in the next section.

2. Research Procedures & Collected Data

The data collection procedures followed the same protocol for both data sets collected in 2015 and 2021. Institutional Review Board (IRB) approval is attained for the data collected from both institutions for the same research questionnaire. The data collected in 2015 and 2021 were from universities located on Midwestern and Northeastern sides of the United States respectively. For simplicity, we call the Midwestern university I1 and northeastern university to be I2. The research participants responded to the same research questions with the objectives outlined in the previous section. All 17 and 20 participants of I1 and I2 institutions received compensation for their participations to both written and video recorded interviews. The quantitative

nature of the data is based on the written responses of the research participants while the qualitative nature of the data is driven by the follow-up questions to the written responses to have a better understanding of written responses. Statistical analysis of the responses to the research questions are analyzed by using both the qualitative and quantitative responses. The results displayed in this work would not only help calculus (and mathematics) educators to understand what STEM students would be interested in using for solving calculus questions but would also help them to find ways to guide students towards technologies that they may use to enhance calculus education of STEM majors.

The following three sections are dedicated to qualitative and quantitative analysis of the research participants' technology preferences. The three research questions' calculus conceptual coverage consisted of function graphing, solving definite integrals, and calculating power series or error terms. What follows is the section that contains the analysis of the impact of six years on the technology preferences of the STEM students. The last section contains a summary of the research conducted and concluding remarks.

3. Analysis of Technology Choices for Graphing Functions

In this section, the technological choices of the research participants to solve the function graphing question is analyzed both qualitatively and quantitatively. The goal of the research question below was to investigate the students' technology choices to graph a given function.

Q1) 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	4. C++	7. MATLAB
2. Excel	5. C#	8. LabVIEW
3. C	6. Fortran	9. Other____

The results of this question were skewed for I1 participants; The most popular choice among the students with 41% was the use of a Texas Instrument (TI) calculator. The other preferred technologies included Excel, LabVIEW, Mathematica, MATLAB, and Wolfram Alpha. All these technologies were either used as a part of the coursework within the specific STEM major students' curriculum or the students learned these technologies during high school years [1]. The specific distribution of research participant choices is outlined in Section 6.

The analysis of the collected data indicated software choices of students based on the technologies' accessibility and ease of use as well as their experiences with the technology and familiarity. The long lasting T.I. calculator use that was carried over from high school years to university education was the major technology choice. All technologies chosen by the students were the ones that they were instructed about how to use for calculus specific applications; there was no specific technology that was chosen by any student through self-exploration or recommendation. Majority of the students selected a technology based on its simplicity, or the ease oftechnology's use depending on the belief of the student. For instance, one of the students believed that Excel would be the easiest tool to solve the question among any other technology even though the student knew how to use a calculator for such an application. Another example is the choice of MATLAB to graph a function because of familiarity with technology. Such familiarity is based on prior course experiences and qualitative analysis of the data revealed that such experience does not depend on calculus

sequence courses.

The results obtained for institution I2 participants for graphing a function were much more skewed towards the use of a T.I. calculator. About 69% of the participants preferred to use one of the T.I. graphing calculators. MATLAB was chosen by 29.4% while MS Excel was preferred by 11.8%. The remainder of the participants declared to used Desmos, a web-based resource for graphing functions. Desmos was a choice based on recommendations and self-explorations.

Overall, the participants' technological choices of students in both institutions fall in at least one of the following categories for graphing a function:

- Simplicity
- Experience
- Familiarity
- Accessibility

Next section outlines the analysis of technology choices of STEM students for calculating integrals similar to the way it is analyzed in this section.

4. Analysis of Technology Choices for Calculating Definite Integrals

STEM students' choices to solve a definite integral question is analyzed qualitatively and quantitatively in this section. The research question is designed by the research team to observe student preferences to calculate a definite integral by hand or by using a technology. The students are asked to choose a technology with the justification of the choice. The goal of the question is to investigate STEM students' interest in solving a problem by either using one of the integral techniques that they learn in calculus or by using technology.

Q2) 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
2. Calculator
3. By hand
4. Other ____

The most popular answer chosen by I1 institution participants was to solve the question by hand; The associated percentage was 30%. One of the students decided to solve the problem by hand because of not being good at programming. Another participant chose to solve the question by using specifically a TI-84 calculator because he/she is the most comfortable with this choice. In the case of using a computer program required, the student declared to use Symbolab and Mathway as alternatives to the use of TI-84 calculators. One of the rare responses was that 17% of I1 participants' interest in using Wolfram Alpha to solve a definite integral due to its ease of use. Another rare method was the use of LabVIEW as a computer program to solve the question that was recently learned by the participant as a part of a numerical methods course. MATLAB was chosen by 9% of I1 students due to its predefined functions that were noted to save time.

The technology interest of I2 institution participants to solve a definite integral was similar to I1 institution participants' interest: Approximately 53% of the students' preferred method was to solve a definite integral problem by hand. The next most popular response was the use of Matlab by 24% of the participants. Calculator was the choice of the rest of the participants that indicated the limited choices of the STEM students from a technological perspective.

Overall, the participants' technology choices are categorized into one or more of the following categories for calculating definite integrals.

- Preference
- Saves Time
- Easy to Use
- Experience
- Comfort

Next section outlines the analysis of technology choices of STEM students for calculating power series related numerical values and graphs.

5. Analysis of Technology Choices for Power Series Calculations

Technology choices of both institution participants' quantitative and qualitative responses to calculate the power series terms and error values are analyzed throughout this section. Some of the details of the data analysis collected will be outlined in the next section.

The participants were initially mandated to choose a technology without mentioning determining a solution by hand as outlined in Q3 below; The choices given were either the use of a calculator or a software package to solve a power series question that requires calculus knowledge. The goal of the question was to analyze students' numerical value or error term calculation preferences for a given power series.

Q3) 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
2. Excel
3. C
4. C++
5. C#
6. Fortran
7. MATLAB
8. LabVIEW
9. Other _____

The top two choices of I1 institution research participants after oral interviews were determined to be Matlab (64.7%). These students had prior experience with MATLAB, and they stated that they can perform tasks quickly. The other choices included Mathematica, Labview, Python, Wolfram Alpha, and C++.

Institution I2 participant response choices were heavily distributed towards calculator and MATLAB use by 50% and 31.25% of the participants respectively. Excel was chosen by 12.5% of the participants while 6.25% of the students chose to solve the question by hand only. This outcome indicated that I2 institution students, aside from MATLAB choosers, were mainly not interested in coding to solve the problem and they didn't know how to solve such a problem.

A comprehensive analysis of the collected data indicated the technological choices of the research participants to be based on the following categories for calculating numerical values of power series or error terms [1]:

- Experience
- Familiarity
- Ease of use
- Comfort

Changes in technological choices of students over the years are outlined in the next section.

6. Changes of STEM Students' Technology Choices Over Years

In this section, we will discuss the changes in the technology choices of STEM majors over the six-year period outlined in this work. Comparison of the results attained for overlapping questions on the technology preferences of the STEM students would be the strong indicator of the impact of time on students' technology preferences for solving calculus questions. Participating in STEM students completed the first two calculus courses of a three-course calculus sequence. Both research methodologies received Institutional Review Board (IRB) approval. The correlation analysis to be explained in this section helps with investigation of further understanding of STEM students' technology preferences and the impact of time on these choices. The goal in this section is to observe if students' technological choices have changed over the six years and if they tend to choose paper-pencil solutions over the use of technology. We performed a correlation analysis on the three technology questions separately.

Question Q1 stated in Section 3 is used for function graphing preferences of the two institutions' research participants. The correlation analysis presented in this section is based on the number of technology choices for each different technology for the two groups rather than focusing on consistency of individual choices of each participant for all three questions. For instance, there were 8 and 6 participants that chose to use calculator in 2021 and 2015 for graphing a function, respectively. It is determined that there is 84.5 % correlation on the collected data for the current and past data indicating a strong correlation of technology use for graphing a function. This can be viewed as a very good predictor that the students' technological choices for graphing a function did not change much over the years. The correlation analysis indicated the use of TI calculators' and Matlab's use as the main driver of the choices. Figure 1 below outlines these choices.

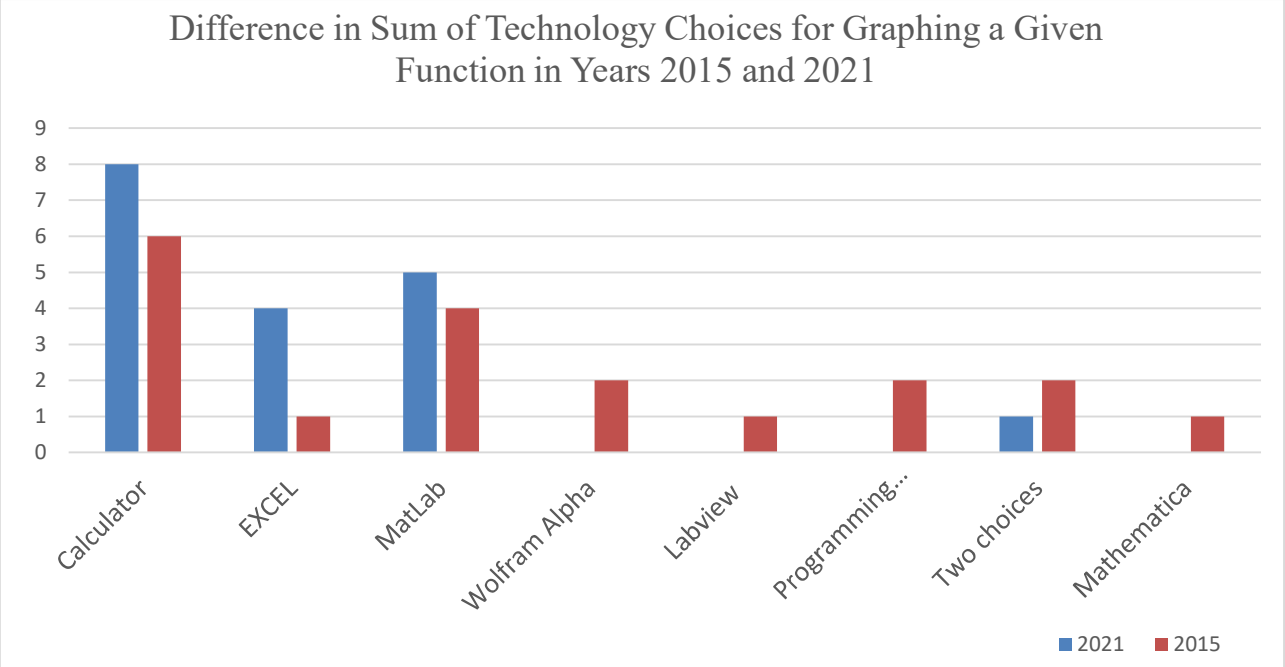

Figure 1. Comparative technology choices of STEM students for graphing a given function.

The data in Figure 1 displays the category-based differences in technological choices of the students for graphing a function. There are consistencies in this data for choices of several technologies. The "two choices" category in this figure is based on the participants' interest to use two different technologies without distinguishing one from the other. Calculator was the top choice for both years of data, which shows that the students in 2015 compared to 2021 are still most comfortable with using a calculator to graph a given function. None of the research participants preferred to solve this question by hand in either one of the two years. Programming languages such as C++ and C# were rare choices of the participants for the data collected in 2015 while these technologies were not chosen by those that participated during the research conducted in 2021; instead, the use of Microsoft Excel was much greater in the data collected in 2021 from I2 participants. These differences are due to the differences in the backgrounds of the students in the corresponding STEM major; The data analyzed in 2015 had computer science student participants while the participants of the data analyzed during 2021 were mainly mathematics, industrial and mechanical engineering majors. C++ and C# for graphing a function were rare choices of computer science students even though they were not taught how to use these programming languages in the calculus courses. The choices of engineering majors in both institutions were mainly Excel, Matlab, and calculator-based technologies covered throughout the courses of the associated curriculums.

Question Q2 presented in Section 4 is used for understanding changes in STEM students' technology choices for solving a definite integral question over the years. The correlation between the two collected data sets is observed to be 73.4% that can be considered as a mildly strong positive relationship between the choices of STEM students assuming that a correlation above 50% is said to be a positive correlation. Figure 2 below displays the differences in the choices of the STEM majors for both data sets.

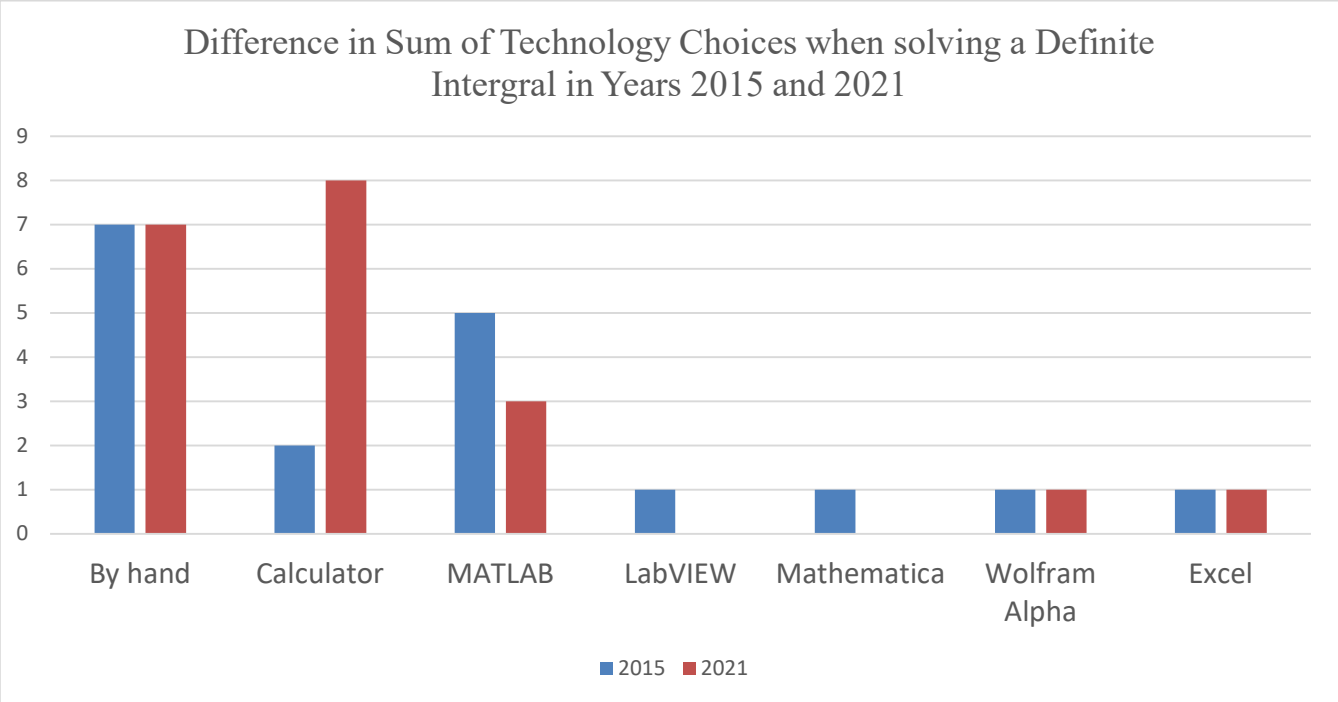

Figure 2. Comparative technology choices of STEM students for solving an integral question.

There are two major differences between the two data sets considered for comparison; There is an increase in the number of students who preferred to solve the definite integral by hand in both institutions. In addition, institution I2 participants preference to use a calculator increased to solve a definite integral when compared their technology preferences for Q1. As can be seen in Figure 2, majority of both institution participants' preferences were to solve a definite integral question by hand. The number of Matlab choices increased for solving Q2 remained similar to solving Q1. None of the I2 participants preferred to use a programming language other than MATLAB that required coding.

Third, and last, we compare the technology choices for the two institution participants for solving a question related to power series and which technology they would choose to solve such a question. The analysis indicated a correlation coefficient of 79.19% for the two data sets indicating a good correlation between the two data sets. When compared to the technological choices made by the participants for solving Q1 and Q2, the categories of technology choices did not change for solving Q3. Figure 3 shows the categories of research participants' preferences for solving a power series of questions in the two data sets.

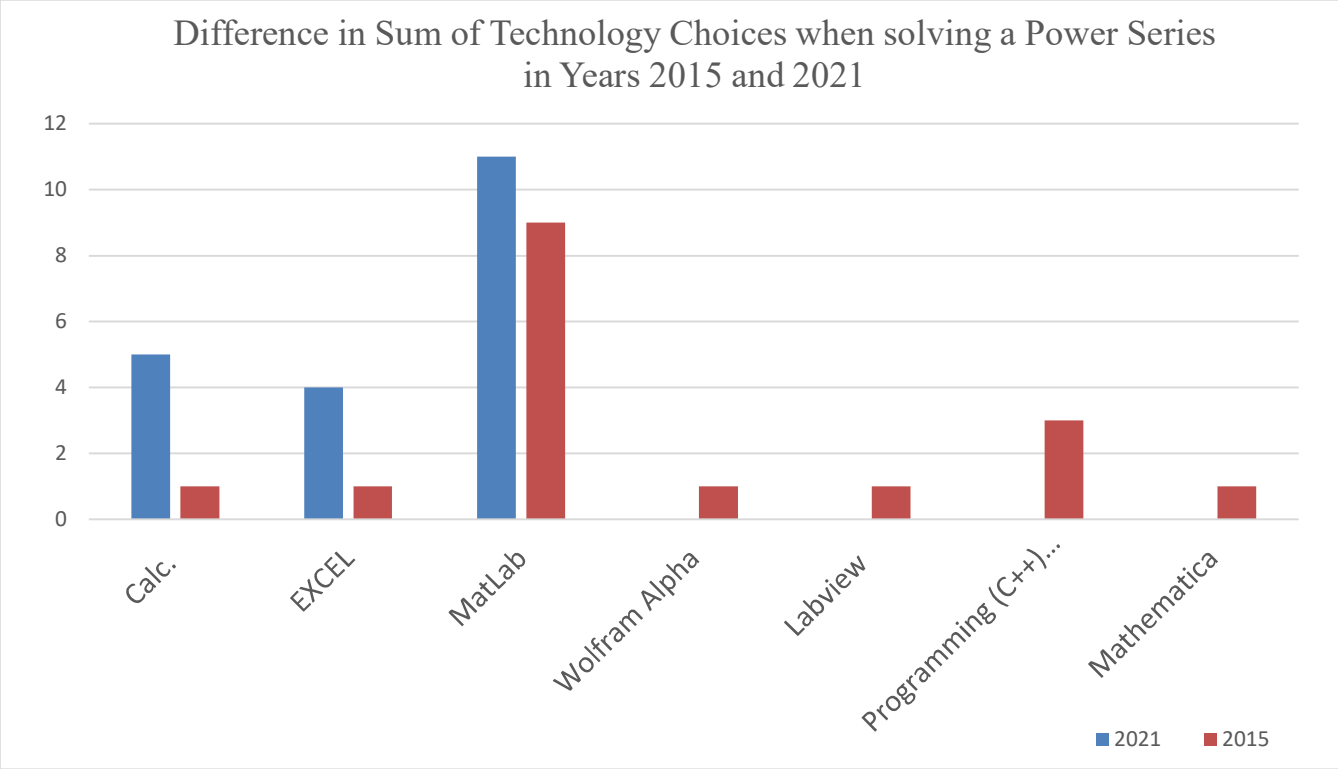

Figure 3. Comparative technology choices of STEM students for solving a power series question.

There is a dramatic increase in the interest of STEM students in using MATLAB in both years as can be seen from comparison of Figures 1-3. There were no students who preferred to solve the question by hand in either one of the collected data sets. Overall, there is an increase in the technology choices, particularly programming language choices such as C++, C#, LabView, and Mathematica when compared to the choices made for both Q1 and Q2 responses. This outcome may be the indicator that the STEM students prefer to use more sophisticated programming languages as the "conceptual intensity" of the question increases. This

can be due to two possible reasons: (1) The programming languages they learned for solving such questions in the STEM courses allow them to make such choices regardless of their comfort level; (2) Participants preferred to use the technology that they are most comfortable with or without knowing how to solve such a question because they are neither comfortable with any other technology nor by hand to solve such a question.

7. Conclusion

In this work, we investigated two different institutions' STEM students' technology choices during two different years for solving three different calculus concept related questions. The data collection procedures followed the same protocol for both data sets collected during 2015 and 2021 years. Institutional Review Board (IRB) approval is attained for the data collected from both institutions for the same research questions. The data collected during years 2015 and 2021 were from a university located on Midwestern and another university located on the Northeastern sides of the United States respectively. For simplicity, we abbreviated the Midwestern university as I1 and northeastern university as I2. The research participants responded to the same research questions with the objectives outlined in the previous section. All 17 and 20 participants of I1 and I2 institutions received compensation for their participations to both written and video recorded interviews. The results outlined in this work were based on both the qualitative and quantitative data collected from the research participants. The technology choices of the participants were analyzed based on function graphing, integrating functions, and power series concepts. The data collected from institution I1 participants' analysis resulted in the following:

- T.I. calculator was the most popular choice of participants. The next popular choice was the use of MATLAB software. Other preferred technologies included Excel, LabVIEW, Mathematica, and Wolfram Alpha.
- The most popular answer to determine a definite integral was by hand. The second most popular response was MATLAB while the third most popular option was using a T.I. calculator. Symbolab, Mathway, Wolfram Alpha, LabVIEW and MATLAB were other preferred technologies of the participants that were determined during the interviews as possible options considered by the participants.
- The top two choices of I1 institution research participants after oral interviews were determined to be Matlab (64.7%). These students had prior experience with MATLAB, and they stated that they can perform tasks quickly. The other choices included Mathematica, Labview, Python, Wolfram Alpha, C++, and C#.

The data collected from institution I2 participants' analysis resulted in the following:

- The use of a T.I. graphing calculator was the most popular response chosen by the participants to graph a function. MATLAB was chosen as the next best option while MS Excel was the third preferred option by the students. The remainder of the participants declared to used Desmos, a web-based resource for graphing functions.
- Approximately 53% of the students' preferred method was to solve a definite integral problem by hand. The next most popular response was the use of Matlab. Calculator was the remaining answer that indicated the limited choices of STEM students from a technology perspective.

- Calculator is chosen by 50% and MATLAB is preferred by 31.25% of the participants to solve a power series related question. Excel was the third most popular choice of participants.

Overall, taking all three technology related questions into account, a strong interest of students to use a calculator is likely due to their calculus course and high school experiences for graphing a function that is seen for both institution participants. The most popular choice for solving a definite integral related question was by hand for both institutions. Lastly, the technological choices of the participants to solve a more sophisticated calculus question than Q1 and Q2 such as a power series question resulted in both institution participants choosing either a programming language or a calculator. From a technology choice standpoint, the technology preferences of STEM students such as calculator, MATLAB and Excel did not change over the years. The main technology choices of the participants appear to be the familiarity with the corresponding technology.

STEM educators and researchers can use the results of this study in many ways. The common technology preferences of both institution students appeared to be the use of calculator and MATLAB. MATLAB was the most popular programming language choice for solving the three questions. Students' choices for solving a definite integral question indicated their lack of confidence in the use of technologies they learned for solving such a question. STEM professors can use certain technologies to better their mathematics education in their courses. For example, both Symbolab and Desmos are free online resources that students may enjoy using. The findings of this research showed that many students do not choose programming languages as a technology due to either lack of knowledge or confidence in programming. Web-based resources and computing technologies can be used to form a strong foundation of the students to solve many different calculus-based STEM questions. Several technologies can be taught extensively by redesigning STEM courses to include more technologies to help students better solve calculus questions since calculus questions are at the heart of STEM education. We encourage researchers and educators to further investigate along theline of this research. It is essential to learn and improve STEM students' technology preferences to solve calculus questions.

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