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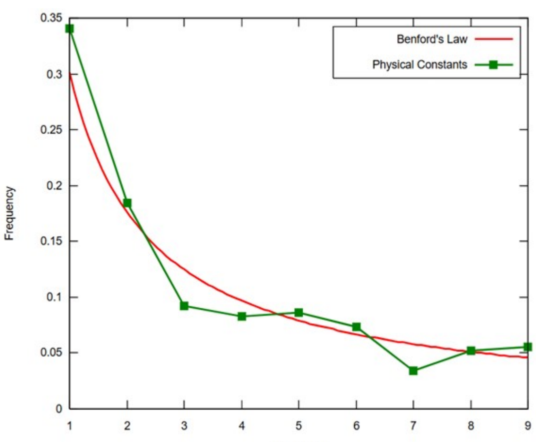
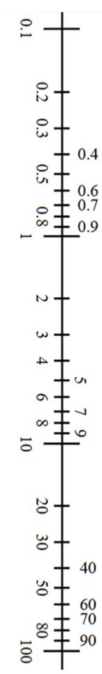
Benford's Law and Python Coding

Philip Weinsier, TIIJ Editor-in-Chief

Numbers are at the heart of and the foundation for design, analysis, and decision-making across all engineering-related disciplines. Numbers are not just important; they are the language of the profession. In fact, engineering is fundamentally about quantifying physical phenomena. Thus, without numbers, it would be impossible to model, predict, or control systems. Engineers measure physical properties (length, mass, time, force, etc.) and express them as numbers to ensure accuracy and repeatability. In fact, most engineering problems are solved using equations where numbers represent variables, constants, and results. Probability and statistics allow engineers to assess risks, predict outcomes, and make data-driven decisions. And, dimensionless numbers enable universal comparison of physical phenomena across different scales and systems.

For example, civil engineers calculate bridge load capacity using calculus and geometry; electrical engineers apply trigonometry for AC circuit analysis and complex numbers for signal processing; mechanical engineers use differential equations to model heat transfer or vibration; and, aerospace engineers use dimensionless numbers to scale model tests to full-size designs. But you certainly knew all of this. My point here is to introduce a numbers "game" that perhaps you have not heard of: Benford's Law. This law predicts that the leading digits of naturally occurring numbers will have a higher frequency of smaller digits, such as the digit 1 (30.1%), and a lower frequency of larger digits, such as the digit 9 (4.6%).





This graph shows the frequency of first-digit significance for physical constants plotted against Benford's Law. Picking a random x position uniformly on the number line of this logarithmic scale bar, the first nonzero digit of the number will be 1 roughly 30% of the time.

Analyzing numbers in a dataset according to Benford's Law not only broadens the understanding of numbers, but it can also highlight whether the data contain anomalies that should be investigated. Benford's Law has been a valuable tool across analytical disciplines making it a useful theory of numeric fluency and has been a valuable tool for validating datasets across disciplines. Specifically, Benford's Law, also known as the first-digit law or the law of anomalous numbers, describes the frequency distribution of leading digits in numerical datasets. That is, the probability $P(d)$ that a number has a leading digit, d (where, d can range from 1 to 9), is given by

$$P\left(d\right) = \log_{10}\left(1 + \frac{1}{d}\right)$$

This tells us that the number 1 will appear as the first digit roughly 30% of the time, while 9 will appear less than 5% of the time, rather than the uniform 11.1% expected if digits were equally likely. The law also extends to second digits, third digits, and combinations of leading digits. Benford's Law arises naturally when numbers span multiple orders of magnitude and are distributed logarithmically. If the logarithms of numbers in a dataset are uniformly distributed, smaller leading digits occupy larger intervals on a logarithmic scale, making them more likely to appear. This is common in datasets generated by power-law processes, such as populations, financial figures, or physical constants. Applications for Benford's Law include

- Fraud Detection: widely used to detect anomalies in financial records, tax returns, and accounting data. Deviations from the expected distribution of leading digits can indicate manipulation or fraud.
- Data Analysis: analysts use the law to verify the authenticity of datasets, including stock prices, billing amounts, and social media metrics.
- Scientific and Engineering Data: here the law applies to measurements such as river lengths, electricity bills, and physical constants, helping to identify errors or inconsistencies.

In the featured article (p.5), the authors present a classroom exercise that includes files and instructions to allow students to gain hands-on experience with Benford's Law and Python programming to show students that digits in natural numbers occur in predictable frequencies. In addition, the case illustrates the utility of Python to manage the analysis from the raw data files through the cleaning, analysis, and visualization of the output. The case was designed to be a useful application of mathematical theory as well as a reinforcement of Python programming skills for students in analytical disciplines.

Editorial Review Board Members

Benford's Law and Python Code: A Proposed Exercise for Engineering and Other Analytical Disciplines

Steven A. Harrast, Central Michigan University; Jaeyoon Yu, Central Michigan University

Abstract

Engineering, scientific, and other analytical disciplines rely heavily on an advanced understanding of numbers as well as the ability to build models and process pipelines using modern programming tools. Accordingly, the authors propose an exercise that makes use of Benford's Law and Python code to show that digits occur in predictable frequencies according to a logarithmic function known as Benford's Law. This law predicts that the leading digits of naturally occurring numbers will have a higher frequency of smaller digits, such as the digit 1 (30.1%), and a lower frequency of larger digits, such as the digit 9 (4.6%). Analyzing numbers in a dataset according to Benford's Law not only broadens the understanding of numbers, but it can also highlight whether the data contain anomalies that should be investigated. Benford's Law has been a valuable tool across analytical disciplines making it a useful theory of numeric fluency.

As a classroom exercise for use in analytical disciplines, the accompanying exercise based on Benford's Law not only illustrates the properties of naturally occurring numbers but also reinforces Python programming skills. While the law itself has practical significance, the reinforcement of Python programming skills is another expected benefit of this case. Many statistics, computer science, and engineering applications rely heavily on computer programming, and Python skills are often fundamental to these disciplines. Similarly, the authors highlight necessary steps in the data analysis pipeline and trace step-by-step through the classroom exercise including uploading, cleaning, analyzing, and visualizing the data. The code for the lab (available at the links provided in this article) runs as a Jupyter notebook on Google Colab. Google Colab is available free on the Google Drive to anyone who has a Google account. The lab plainly shows the power of Benford's Law as well as Python code for teaching theory and application to students in analytical disciplines.

Introduction

Benford's Law (Benford, 1938), originally published in 1881 by Simon Newcomb (Newcomb, 1881), describes the expected frequency of particular digits in naturally occurring numbers and has been a valuable tool for validating datasets across disciplines (Nigrini, 2012). Benford's Law is an element of advanced numeric fluency and finds direct application in statistics and computer science as a data validation tool that may be used alone or as a component of the processing pipeline (Berger & Hill, 2015; Nigrini, 2012). Beyond the use of Benford's Law in the accompanying lab, the Python programming language is also very important in analytical disciplines and has been reported as the most popular programming language in the world (TIOBE Software, January 2026). It is highly regarded in statistics, computer science, engineering, and across analytical disciplines (IEEE Spectrum, 2025). The accompanying exercise is a natural method of demonstrating both an important law of numbers as well as the utility of the Python language.

The Benford's Law exercise presented here was written to be useful in various analytical disciplines. In statistics and computer science, the law itself has practical significance as a method of examining the quality of the data, while in engineering the law may be viewed as teaching more advanced numeric fluency and/or as an illustration of the practical features in Python. The strength of this case is that it provides theoretical understanding of the properties of numbers as well as an application of Python tools that reinforces necessary programming skills. As an outcome, students are expected to better understand both the theoretical implication of Benford's Law as well as how to model an analysis, create a processing pipeline, and visualize data using Python.

In the accompanying exercise, students are asked to run the Python code in the Jupyter notebook and observe and discuss the results. Each segment of the code is explained in the text, giving students the opportunity to both see the theory behind Benford's Law at work as well as observe how Benford's Law is effectively modeled using Python code. The written code and datasets should run as shown; there is no reason to make any changes, unless students or faculty wish to experiment with other datasets. The demonstration of Benford's Law in this analysis is programmed in Python using a Jupyter notebook (.ipynb file) and is executed on the Google Drive in Colab, although any programming environment that is capable of running an .ipynb file would suffice. Colab was used because it requires no setup configuration and is available to anyone who has a Google account.

Materials

Students need to have a computer with access to a Google Drive to use Colab and the Jupyter notebook that analyzes the data. If they do not have a Google Drive, they will need to either set one up or work in another environment that will run a Jupyter notebook file. In addition to the Jupyter notebook, two data files are also needed: 1) benford_data_pcard.csv and 2) benford_data_random.csv. All files can be downloaded from GitHub at the following link:

https://github.com/harrast/benfords_law_code_files_2026/tree/main/Benford%20File

To ensure the files are available to students, it is recommended that the files be placed in a shared directory that students can access to download to their own device. The same effect can be achieved by loading the files onto a learning management system such as Blackboard, if one is available. The total storage for the files including all necessary files for the exercise is only about 1MB, so storage should not be an issue. Based on a similar case that was used previously in classes, it is recommended the class instructor begin the case with a brief presentation on the theory of Benford's Law, perhaps in the form of a slide (PowerPoint) presentation. After the theory presentation, students can begin, and often finish the case, in one class period because the Python code is already written. Being able to code in Python is not a requirement, but students would certainly understand the case more easily if they have had some Python coding experience, which seems to be fairly common in technical majors.

As far as issues to anticipate, some students may be less familiar with the Jupyter notebook interface or may misplace data files. It is helpful if an instructor, or someone who has completed the case previously, can be on hand when students start the case in the event that students need a little coaching. In collecting feedback on the case, students report that their perceptions of numeric datasets have completely changed. Where they originally believed that digits occurred in random frequencies, they now have an informed, theory-based perspective. Given that many technical majors have a significant Python coding element, students could also make simple modifications to the Python code to analyze additional datasets as an extension of the project.

Libraries

The first part of the exercise discusses how Python uses various specialized libraries. Each of the libraries must be individually called before using it in the programming code. It is customary, but not required, to call the libraries in Python at the beginning of the program. Once called, the libraries are available throughout the execution of each section of the code. The given code imports the libraries. The packages section highlights four of the most commonly used libraries in Python—numpy, pandas, mathplotlib, and math. Each of these packages is briefly described next.

Table 1. Python libraries for data analysis.

Library	Description
numpy	used to handle multidimensional arrays
pandas	used for two-dimensional arrays
mathplotlib	used for plotting data
math	used math functions

Students are asked to review the links to these libraries and answer a simple question.

Question 1: Which package do you think you might need to calculate logarithms?
Answer: The math library is used to compute logarithms.

Data

The data for this exercise, as well the Jupyter notebook containing the program, are located at this link:

https://github.com/harrast/benfords_law_code_files_2026/tree/main/Benford%20File

The code is executed by clicking on the code sections in the Jupyter notebook then pressing shift+enter. The code windows need to be run one by one from beginning to end or an error may be returned. When the code initiates the import, the system will request a data file. The file, Benford_data_pcard.csv, has been supplied at the URL in the previous paragraph. As part of the normal data analysis pipeline, the data will need to be cleaned before they can be used because negative numbers and decimals will cause errors when digits are counted. When this code is executed (shift+enter), the program will read the data contained in benford_data_pcard.csv, convert negative values to positive, and move the decimal three places to the right so that $0.01 (one cent) becomes 10. Table 2 provides summary statistics that were printed during the execution of the code and which show that the smallest value (min) is now 10. This provides two digits to analyze under Benford's Law and eliminates the issues with negative numbers and decimals.

Table 2. Summary statistics.

Statistics	Values
count	420,595
mean	409,097
std	2,185,998
min	10
25%	35,000
50%	110,000
75%	339,960
Max	551,390,700

Students are asked to consider what would happen if the data were not conditioned for this exercise.

Question 2: Why is it important to multiply all the numbers in the dataset by 1000 given that the smallest number in the data is 0.01? Do you know what will happen if the computer looks for a number and encounters a decimal or a minus sign?
Answer: Multiplying by 1000 is necessary to convert the smallest decimal value of 0.01 to 10.0 in order to have two digits to analyze. If the non-numeric characters are not removed, an error will be generated when the system attempts to read the non-numeric characters as numbers.

As the next step in the analysis pipeline, the first digits must be extracted and counted so that their frequencies can be computed and compared to the Benford distribution. The code in the case extracts the first digit and computes the frequencies of each digit. Table 3 shows the computed digit frequencies for the purchase card dataset.

Table 3. First-digit frequencies.

Digit	Frequency
1	0.279
2	0.185
3	0.127
4	0.097
5	0.080
6	0.061
7	0.054
8	0.046
9	0.072

Plotting

Visualization is a critical part of the data analysis pipeline. Part of the appeal of this case is the visual representation of the data so that it is plain to the eye that there is a pattern of digit frequencies. Figure 1 shows a plot of the first-digit frequencies contained in the supplied dataset, benford_data_pcard.csv. If a different dataset is supplied by the user, the results will vary but should still approximate the logarithmic distribution described by Benford's Law. It is evident from Figure 1 that there is a pattern in the digit frequencies where lower digits often, but not always, have a higher frequency than higher digits. The phenomenon of lower digits having higher frequencies is an artifact of growth functions. To grow from a population of 100 organisms to 200 organisms is to double, or a 100% increase. Increasing from 800 organisms to 900 organisms is only a one eighth or a 12.5% increase, which takes about one eighth as much time as a 100% increase. It takes much longer for the population to double than increase only 12.5%, therefore a lower digit, such as the digit 1, is much more likely to be found as the first digit than the number 8. The same is true of bank accounts and prices, which take more time to double than they do to increase by one eighth. But the question is whether Benford's Law accurately predicts these digit frequencies.

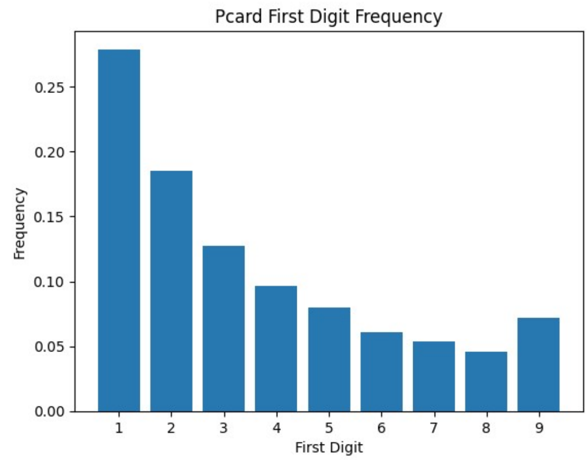


Figure 1. First-digit frequencies for purchase card data.

The code in the Jupyter notebook calculates the Benford's Law probability of each digit as $\log_{10}\left(1+\frac{1}{d}\right)$, where d is the first digit—e.g., for the digit 5, this would be $\log_{10}\left(1+\frac{1}{5}\right)$ or 0.07918. The actual digit frequency is then plotted with the Benford distribution superimposed. Table 4 shows the Benford frequency distributions for the first digit 1–9.

Table 4. Benford frequencies by digit.

Digit	Benford Frequency
1	0.301
2	0.176
3	0.125
4	0.097
5	0.080
6	0.067
7	0.058
8	0.051
9	0.046

By examining Table 4, one can see the probability of each digit, 1–9, occurring as the first digit of a number—e.g., the probability of the first digit being 1 in a number is 0.30103 or 30.1%. This tells us that when viewing a dataset including populations of cities, bacteria, bank accounts, taxable income, credit card transactions, the digit 1 should appear as the first digit in 30.1% of the numbers, provided that the sample is large enough to approximate the population. The number that is least likely to appear in the first position is 9, which has a probability of 0.04576 or 4.6%.

Students are asked to consider why the number 1 is more likely as the first digit than the number 9.

Question 3: Can you explain why you think the number 1 is more than six times as likely as 9?
Answer: The number 1 is much more likely as the first digit because it takes a longer time for the magnitude of a population to double from 1 to 2 or from 10 to 20 than it does for a magnitude to increase by only 11%, such as increasing from 9 to 10. Since it takes a population a long time to double, the number 1 endures as the first digit for about 30.1% of the time, while the number 9 is the first digit only about 4.6% of the time.

Figure 2 shows a plot of the Benford frequences from Table 4 to show the probability of each digit, 1–9, while Figure 3 shows a comparison of the purchase-card amounts to the Benford frequencies.

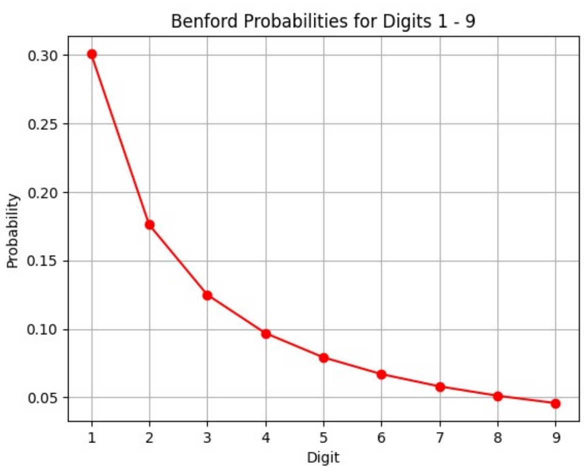
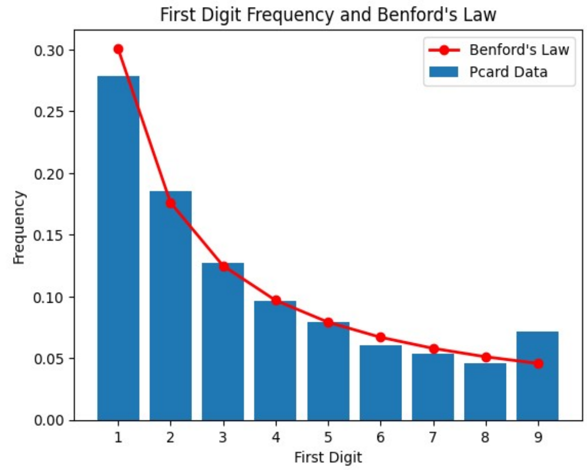


Figure 2. Benford first-digit probabilities.

While the first-digit frequency of the purchase card transactions does not fit perfectly within the Benford predicted frequencies, there is a distinct relationship. The digits 3, 4, and 5 are nearly a perfect match, while other digits have some variability. Regardless of what data are used, as long as they represent the magnitude of some object, it is very likely to follow a Benford distribution. Additional depth could be introduced into the case by executing a Chi-square goodness-of-fit test to determine statistically how well the actual digit distribution matches the theoretical Benford distribution. This is left as an optional exercise to be done according to the discretion of the instructor.

Figure 3. Benford probabilities and actual purchase-card transactions.



Students are asked to examine Figure 3 and determine whether the dataset digit frequency matches the Benford distribution.

Question 4: Does the frequency of the digits in the dataset (blue bars) match the Benford frequencies (red line)? Is it easy to recognize the difference between Benford's predicted frequencies and the dataset values?
Answer: Clearly, the actual data and the Benford distribution are correlated, although a few of the digits differ in the actual dataset. It is easy to see the difference between the Benford distribution and the actual dataset in the digits 1 and 9. The other digits are quite close**.**

The second-digit test begins by computing the frequencies of the second digit (0–9). Running the code calculates the second-digit frequencies from the dataset. Figure 4 shows a plot of the frequencies.

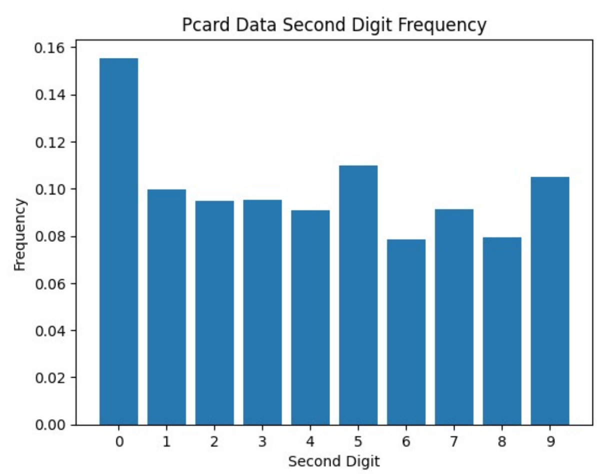


Figure 4. Second-digit frequencies purchase card dataset.

The logarithmic distribution of the second-digit data is much less pronounced than the first-digit test. This is because the growth increments for the second digit are much smaller than for the first digit. Students are asked to calculate the percentage change in two digits and a single digit to highlight why the second-digit test is less pronounced than the first-digit test.

Question 5: If the number grows from 13 to 14, what percentage increase is this? How about if the number changes from 3 to 4?
Answer: If a number grows from 13–14, the increase is 1/13 or 7.69%. If a number grows from 3–4 the increase is 1/3 or 33.33%.

Calculation of the of the second-digit probabilities utilizes the same base $\log_{10}\left(1+\frac{1}{d}\right)$ except that the formula aggregates the probability of all numbers that have a second digit of d, where d is an element in the set 0–9. So, where $d = 1$, the program would aggregate the probabilities of 11, 21, 31, 41, 51, 61, 71, 81, and 91 to determine the probability that d (the second digit) = 1. Table 5 shows the probabilities of the second-digit occurrence calculated using the logarithmic function.

Table 5. Second-digit probabilities.

Second Digit	Probability
0	0.112
1	0.114
2	0.109
3	0.104
4	0.100
5	0.097
6	0.093
7	0.090
8	0.088
9	0.085

Figure 5 shows a plot of the second-digit probabilities from the values in Table 5; note that the graph shows a smooth logarithmic trajectory. The second-digit frequency and Benford's Law combine the theoretical distribution with the empirical data in Figure 6. The second-digit distribution validates the relationship between Benford's Law and the empirical world. While this relationship is not as visually strong as the first-digit test, it still shows a descending frequency as numbers increase in magnitude, the main characteristic of Benford's Law. The relationship between Benford's Law and the first and second digits of a number are examined. The last part of this series of analyses will consider a two-digit test, a test that empirically examines each two-digit number from 10–99.

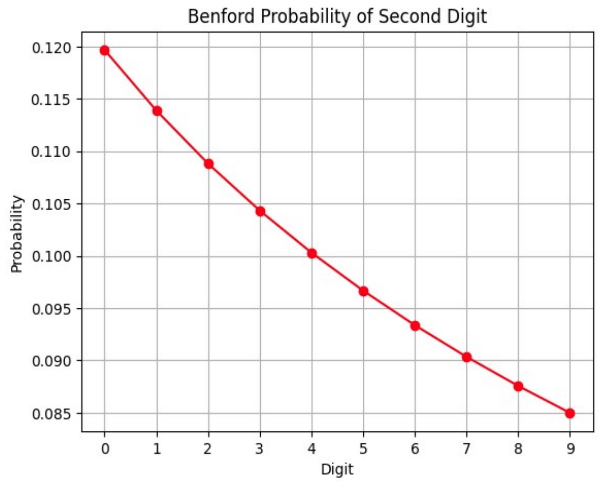


Figure 5. Benford second-digit probabilities.

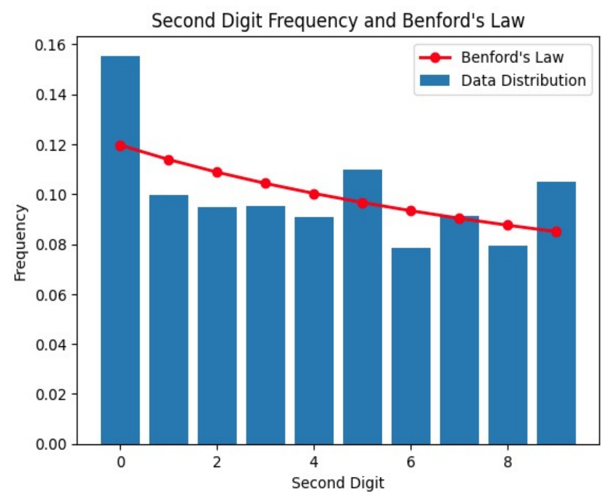


Figure 6. Plot of Benford second-digit theoretical distribution over second-digit purchase card data.

To begin this analysis, the probability of each two-digit number is calculated using a logarithmic function specified by Benford's Law, given in Equation 1:

$$\log_{10}\left(1+\frac{1}{n}\right) \tag{1}$$

where, n is used to avoid conflict with the variable d, which was introduced previously in the Python code.

As there are 90 probabilities, and they are all displayed in the output within the Jupyter notebook file, they will not be listed here, but they will be plotted below. Figure 7 shows a plot of the two-digit probabilities for Benford's Law. Again, the downward sloping logarithmic curve characteristic of Benford's Law can be seen.

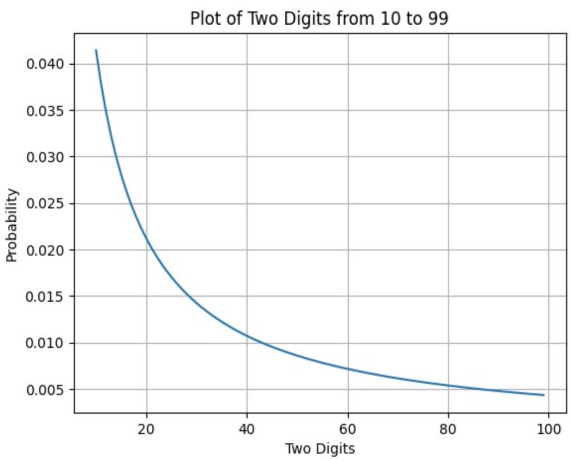


Figure 7. Plot of Benford distribution for digits 10–99.

Above, the theoretical Benford distribution for two digits was computed. Running the code produces Figure 8, which shows the two-digit frequencies from the purchase-card data.

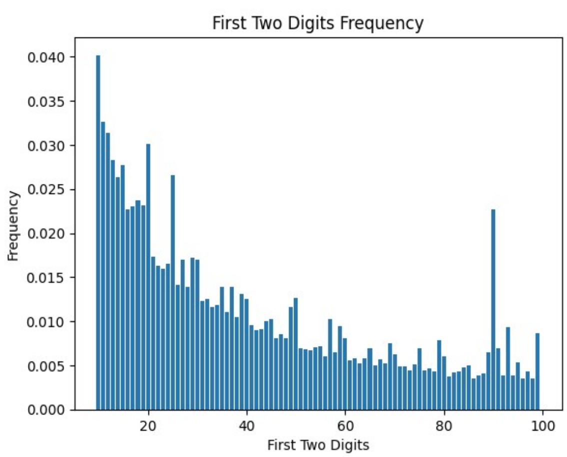


Figure 8. Plot of two-digit frequencies from the purchase-card data.

Students are asked to visually compare the plot of the purchase card data with the theoretical distribution.

<u>Question 6</u>: Does the data look similar to the theoretical Benford two-digit distribution plotted just above? Are you surprised that a dataset consisting of purchase card transactions would have such a correlation?
<u>Answer</u>: While there are some two-digit frequencies that depart from the theoretical distribution, the general shape of the distribution is very similar to the theoretical distribution. Answers may vary, but many students are surprised that digits do occur in predictable frequencies.

In Figure 9, the Benford theoretical two-digit distribution is combined with the empirical purchase-card data.

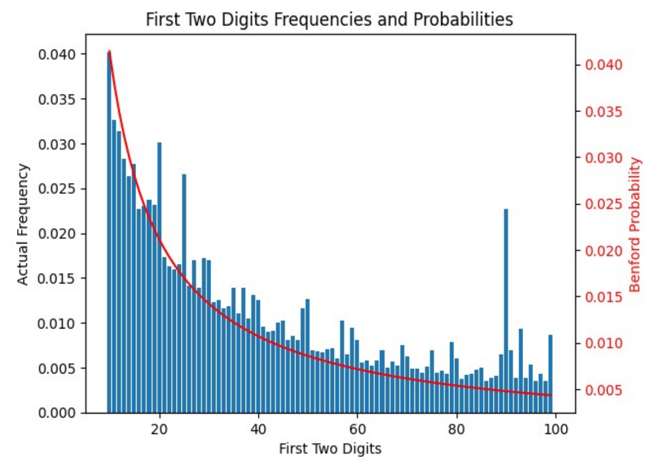


Figure 9. First two-digit frequencies and theoretical probabilities.

While a correlation undoubtedly exists, there are a few critical values that are outside of expectations. Without any kind of documentation for the values in the file, there is no way to perform an audit. However, if an audit could be performed, it would be interesting to analyze the data by purchaser or by item as a stacked bar, though that is beyond the scope of this study. This does, nonetheless, illustrate that one purpose of Benford's Law is to discover which values are outside of expectations so that they can be investigated.

Random Numbers

This part of the analysis will compare the purchase-card data to a set of randomly generated numbers. The random numbers are in the file benford_data_random.csv. The numbers were created using the *Excel* function "=randbetween(10, 10000)" to create 1878 values between 10 and 10,000. There is no particular reason for creating 1878 values except that it is a large enough sample to generate a uniform distribution across all nine first-digit possibilities. A first-digit test is performed on the random values and compared with the purchase-card data to see if there is a visible difference. The random number data can be found in the file at this link:

https://github.com/harrast/benfords_law_code_files_2026/tree/main/Benford%20File

The data must be imported from the file containing the random numbers. The name of the file supplied is benford_data_random.csv. Table 6 indicates how the code in the ipynb file computes the frequency of the first digit in the random number file. Simply looking at the file, one can see that the digit frequencies in the file are similar across all digits. Next, the Benford distribution is plotted against the random values to see if the random values follow a Benford distribution. The expectation is that, because the numbers are randomly distributed and do not represent naturally occurring numbers, they will not fit a Benford distribution.

On the other hand, the purchase-card data analyzed previously did fit a Benford distribution quite closely. Figure 10 shows a plot of the random values; these random values, though, do not appear to follow any particular pattern, much less a Benford logarithmic distribution.

Table 6. Random number digit frequencies.

Digit	Frequency
1	0.110
2	0.107
3	0.117
4	0.115
5	0.098
6	0.117
7	0.121
8	0.103
9	0.112

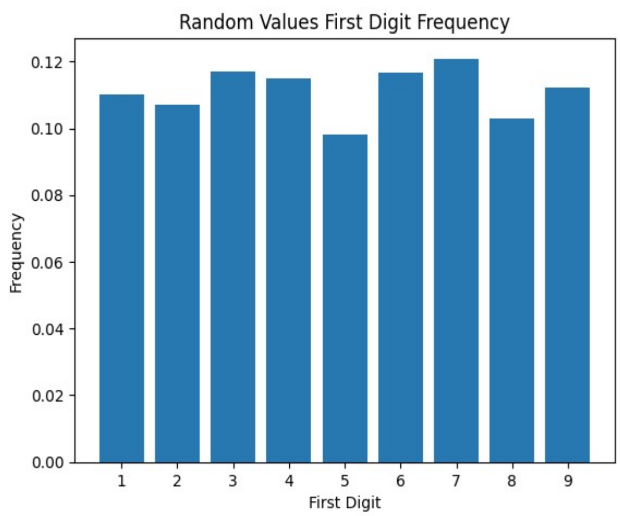


Figure 10. First-digit frequency in random numbers.

Figure 11 shows that, when plotted side-by-side, it is evident that the randomly generated numbers do not follow a Benford distribution, while the purchase-card numbers, the prices of transactions processed on purchase cards, are very close to a Benford distribution. This clearly shows that naturally occurring numbers—numbers representing magnitudes—follow a Benford distribution.

Conclusions

In this paper, the authors proposed the use of a classroom exercise to teach both the theory and the application of Benford's Law as well as reinforcing Python programming skills and the steps in the data analysis pipeline. The exercise analyzes the first, second, and first two-digit combinations of numbers using Benford's Law and plainly shows that digits in natural numbers occur in predictable frequencies. In addition, the case illustrates the utility of Python to manage the analysis from the raw data files through the cleaning, analysis, and visualization of the output. The case was designed to be a useful application of mathematical theory as well as a reinforcement of Python programming skills for students in analytical disciplines. The proposed benefit to students includes gaining greater fluency with patterns of numbers as well as reinforcing the use of Python in analytical disciplines such as engineering, statistics, computer science, and others. A strength of the case is that Benford's Law is an interesting and useful theory in and of itself, while having the added benefit of reinforcing Python and data analysis skills. The case can be downloaded from the link provided here and used as is or modified according to the needs of the instructor.

https://github.com/harrast/benfords_law_code_files_2026/tree/main/Benford%20File

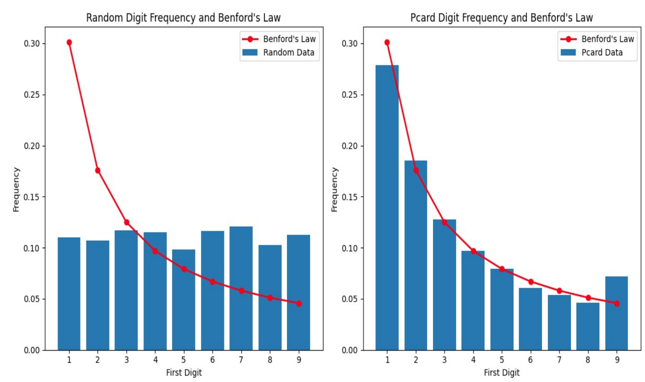


Figure 11. Comparison of random and purchase-card data to a Benford distribution.

In future work, it is expected that the case will be administered to students and feedback solicited to determine what types of improvements should be made to improve its efficacy, including the possibility of having students participate more in the Python coding process or analyzing other data sets. It would be interesting to administer the case to students in various disciplines and to analyze their perceptions.

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An In-class, Hands-on Project for Effective Teaching of An Undergraduate Lean Six Sigma Class

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Abstract

Teaching Lean Six Sigma (LSS) concepts to undergraduate students presents several pedagogical challenges. These challenges primarily stem from students' limited exposure to manufacturing environments, lack of spatial understanding of industrial layouts, and insufficient hands-on experience with production processes and product handling. It is often impractical, both logistically and financially, to organize industrial visits for an entire class each semester to observe real-world applications of Lean Six Sigma principles. To address these limitations, the authors of this current study designed and implemented an in-class, hands-on project utilizing the manufacturing of a paper airplane as a pedagogical tool. An assembly line was constructed within the classroom, complete with designated workstations where students produced paper airplanes to meet a specified takt time. In a typical class of 30 students, six participants were assigned as operators for each production run, which lasted ten minutes. Six runs were conducted to ensure full class participation. The airplane production process consisted of twelve distinct steps; however, to streamline operations, several tasks were combined, resulting in a five-operator assembly line, with the sixth student serving as a test pilot responsible for quality inspection.

The assembly line configuration was modified in successive runs to demonstrate the progressive application of Lean principles. The first run employed a batch production system, followed by a "push" production line, a "pull" system utilizing kanban controls, and, ultimately, a single-piece flow configuration. For each iteration, data were collected on the number of conforming and defective units as well as the work-in-process (WIP) inventory. The production goal was to achieve a takt time of 15 seconds per unit, equivalent to 40 airplanes within a ten-minute interval. Upon reaching this benchmark, students conducted design of experiment (DOE) and applied statistical process control (SPC) techniques to assess process stability and capability. Subsequently, students applied the DMAIC methodology—Define, Measure, Analyze, Improve, and Control—to identify root causes of process variability and implement improvements aligned with Six Sigma objectives, the aim of which was to reduce defects to 3.4 parts per million. This structured experiential exercise not only reinforced theoretical knowledge but also enhanced the students' comprehension of process optimization, waste reduction, and continuous improvement within manufacturing systems. Preliminary observations indicated that the hands-on project substantially improved student engagement and conceptual understanding of Lean Six Sigma principles. Future work will expand the activity by introducing a second airplane design to illustrate the concepts of product mix, load leveling (heijunka), and capacity balancing.

Introduction

Lean manufacturing has its origins in the early twentieth century and is most closely associated with the Toyota production system (TPS), developed under the leadership of Taiichi Ohno. The TPS later became widely recognized in the U.S. as "Lean Manufacturing." Lean manufacturing is a systematic methodology aimed at eliminating waste within production systems, while maximizing overall productivity and value creation. Complementary to Lean, Six Sigma (6σ) is a data-driven methodology focused on reducing process variation, minimizing defects, and enhancing quality and efficiency. Originally introduced by engineer Bill Smith at Motorola in 1986, Six Sigma employs a set of statistical and analytical tools designed to achieve near-perfect quality; specifically, no more than 3.4 defects per million opportunities. When integrated, lean and Six Sigma form a powerful continuous improvement framework: lean emphasizes speed and waste elimination, while Six Sigma ensures accuracy and process stability. Together, they improve productivity, reduce costs, and increase organizational profitability.

Teaching Lean Six Sigma (LSS) principles to undergraduate students in engineering or industrial technology disciplines presents a unique set of pedagogical challenges. Students often lack prior exposure to real-world manufacturing processes and industrial layouts, which limits their ability to visualize and comprehend abstract LSS concepts. This experiential gap necessitates the use of interactive, hands-on learning projects that replicate manufacturing scenarios in a simplified and engaging manner. Such simulations provide tangible learning experiences that bridge theoretical understanding and practical application. One of the most widely used classroom simulations to demonstrate lean manufacturing principles such as pull systems, kanban control, and one-piece flow is the paper airplane assembly line exercise. Numerous variations of this activity have been documented in the literature to illustrate various lean concepts. However, while these exercises effectively demonstrate lean principles, few have incorporated the complementary Six Sigma dimension. Consequently, there is a notable gap in the pedagogical literature regarding integrated LSS classroom simulations.

To address this gap, the authors of this current study developed, demonstrated, and documented a comprehensive in-class LSS hands-on project based on the paper airplane assembly process. The activity was structured at a Green Belt competency level and follows the DMAIC framework. This approach provided students with experiential learning opportunities that encompassed both lean process optimization and Six Sigma statistical control. The paper airplane project offers several educational advantages.

1. Low cost: paper is inexpensive and easily accessible. Fewer than 200 sheets are required per semester, resulting in a total cost of less than five dollars.
2. High student engagement: every student actively participates, enhancing learning outcomes and retention.
3. Ease of implementation: most students are already familiar with basic paper airplane construction, requiring minimal training and typically a single demonstration run.
4. Controlled variation: the uniformity of paper materials minimizes process variation, aligning with the core objectives of Six Sigma. This level of control is often unattainable in other classroom projects, such as those using LEGO components.
5. Enhanced classroom dynamics: the exercise promotes collaboration, engagement, and enjoyment, transforming complex process improvement concepts into an accessible and interactive learning experience.

Overall, this hands-on project provided an effective, low-cost method for teaching integrated LSS concepts in undergraduate classrooms, fostering both theoretical understanding and practical competence.

Literature review

Although LSS has been widely recognized as an effective methodology for process improvement, teaching its principles within academic settings remains a significant pedagogical challenge. Numerous researchers have attempted to enhance student understanding and practical application of LSS by developing simulation-based, hands-on learning activities. Tseng, Akundi, Saavedra, and Smith (2016) compared the effectiveness of a hands-on paper airplane simulation with a computer-based simulation using Rockwell Arena software. Their findings indicated that students achieved better learning outcomes with the computer-based simulation, suggesting that digital environments may provide greater flexibility and analytical insight than purely physical simulations. Similarly, McManus, Rebentisch, Murman, and Stanke (2007) examined the use of the CDIO (Conceive, Design, Implement, and Operate) framework to teach lean manufacturing principles through experiential simulations. This framework closely parallels the DMAIC methodology used in Six Sigma projects. Results from student surveys of the CDIO-based approach indicated strong engagement and positive feedback, with 13% of participants describing the experience as exciting, 40% as good, 25% as illuminating, 19% as hands-on, and 3% as fostering class bonding.

In a comprehensive review, Badurdeen, Marksberry, Hall, and Gregory (2010) examined several existing lean simulation games, including the paper-clip simulation, circuit board simulation, LEGO simulation, and the lampshade assembly exercise. They identified four key limitations common to most simulation-based learning designs: 1) inadequate emphasis on soft-skill development, 2) an overly linear representation of lean principles, 3) insufficient recognition of the facilitator's critical instructional role, and 4) limited realism in simulated environments. Szedlak, Baarsch, and Leyendecker (2021) echoed these findings by identifying 49 different lean training simulations and reporting a continued lack of focus on soft skills, along with limited adaptation of such activities for online or hybrid learning contexts.

Hands-on engagement is considered essential for effective LSS training, as it bridges the gap between theoretical knowledge and practical application. Luttik (2017) emphasized that the use of lean tools and methods during classroom instruction plays a pivotal role in facilitating the transfer of lean production principles from academia to industrial practice. Similarly, Vin and Jacobsson (2017) argued that while simulation-based learning can effectively introduce foundational lean concepts, it may be less suitable for developing the skills required by industrial workers who rely more on experiential and intuitive learning than on formal instruction. To ensure meaningful knowledge transfer, training environments must realistically replicate workplace conditions and integrate theoretical learning with practical experience. This integration becomes increasingly challenging in production and manufacturing education, as highlighted by Elbadawi, McWilliams, and Tetteh (2010).

Building upon this need for authentic learning experiences, Elbadawi, Aichouni, and Messaoudene (2016) developed an innovative, hands-on junction-box assembly project that applied the DMAIC methodology to identify controllable variables, minimize process variation, and eliminate waste. Their work demonstrated the pedagogical value of experiential projects in reinforcing key LSS principles, particularly those related to process optimization, data-driven analysis, and continuous improvement. Collectively, these studies underscore the importance of integrating practical, simulation-based approaches in LSS education. While a variety of lean-focused classroom activities exist, relatively few effectively incorporate both lean and Six Sigma methodologies within a unified learning framework. The current study addressed this gap by presenting a comprehensive, classroom-based LSS project designed to enhance conceptual understanding, promote engagement, and provide students with an authentic learning experience through an accessible and low-cost paper airplane assembly simulation.

The Lean Six Sigma Project

To get started, a baseline was needed. A batch size of five was chosen and a demo run was performed for 10 minutes. Table 1 shows the numbers for good planes, bad planes, and work-in-process (WIP). With these baseline numbers, the DMAIC methodology of process improvement was used to modify the process to eliminate waste and reduce variation. Figure 1 illustrates several key tools and techniques commonly employed in a LSS project. Each phase of the DMAIC framework incorporates distinct tools that make the process improvement effort systematic, data-driven, and sustainable.

Table 1. Batch manufacturing with a batch size of five.

	# Good planes	# Bad planes	Total	WIP
Batch – size 5	1	6	7	27

Figure 1. LSS tools and techniques.

Define Phase

Figure 2 shows the step-by-step, 12-step process for constructing a paper airplane. Lean Six Sigma is a five-phase DMAIC process improvement methodology. Two key tools were applied in the Define phase: the Project Charter and the Gemba Walk. Table 2 shows the Project Charter, which formally defined the problem, goal, business case, and scope of the study. The Gemba Walk, or process walk, involved direct observation of the process to gather first-hand data on workflow and performance.

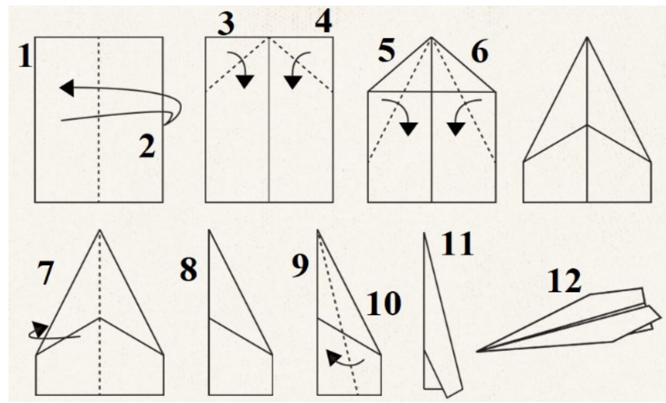

Figure 2. Paper airplane construction.

A preliminary demonstration was conducted by establishing an assembly line comprising five students as operators and one as a test pilot. Figure 3 show how each operator was responsible for specific folding steps: Operator 1 performed Steps 1-2; Operator 2 completed Steps 3-4; Operator 3 carried out Steps 5-6; Operator 4 executed Steps 8-9; and, Operator 5 performed Steps 10-11. Step 7 was just a completed form of Steps 5-6. The final operator tested the planes to classify them as good or defective. The objective at this stage was to calculate the cycle time for each operator, which would inform calculations of lead time and takt

Table 2. Project charter.

Project Charter	
Problem statement	Business case and benefits
Currently the paper airplane assembly line has a huge WIP and more defective planes than good planes. They are not meeting the takt time of 40 planes in 10 minutes.	This project will turn the company from losses to positive profits.
Goal Statement	Timeline
Decrease the number of bad planes from an average of 10 planes to a target of 0 defects by May 1st, 2024. Also, modify the assembly line to keep the takt time.	Phase: Planned completion date Define, Measure, Analyze, Improve, Control
Scope – First/Last and In/out	Team Members
In scope – Assembly line layout, number of operators. Out of scope – Fixtures to aid in making folds.	Person % of time Student 1 10% Team lead 50% Student 2 10%

time. Operator 1 required 6.60 seconds, Operator 2 required 10.28 seconds, and Operators 3-5 required 8.00, 8.92, and 8.87 seconds, respectively. An additional 4 seconds were added to each operator's time to account for material handling, resulting in rounded cycle times of 11, 15, 12, 13, and 13 seconds, respectively.

	Start	Steps 1-2	Steps 3-4	Steps 5-6	Steps 8-9	Steps 10-11
No. of operators		Ω	Ω	Ω	Ω	Ω
Cycle time (Seconds)		6.60	10.28	8	8.92	8.87
+ 4 seconds added for material handling						
Total		10.60	14.28	12	12.92	12.87
Rounded Total		11	14	12	13	13

Figure 3. Process flow showing cycle times for each operator.

Measure Phase

The Define and Measure phases were closely related, as several key measurements were already collected during the initial process walkthrough. In this phase, two tools were emphasized: takt time analysis and operational definitions. The total lead time, based on Figure 3, was 63 seconds. The line was run for 10 minutes (600 seconds) with a production target of 40 planes. Takt time sets the pace of production, as given in Equation 1:

$$\text{Takt time} = \frac{\textit{Total production time}}{\textit{Customer demand}} = \frac{600}{40} = 15 \text{ seconds per plane} \quad (1)$$

This calculation indicated that each operator's cycle time could not exceed 15 seconds to achieve the target output. Although the total lead time per plane (63 seconds) appears inconsistent with producing 40 planes in 10 minutes, this is a common point of conceptual confusion among students. The key distinction is that lead time does not directly determine throughput; rather, maintaining each cycle time below takt time ensures continuous production flow at the desired rate. Operational definitions were developed to ensure consistent data collection. A "good plane" was defined as one that successfully flew and hit any wall of the classroom before landing. A "defective plane" was one that hit the ground before reaching a wall. Establishing these definitions minimized ambiguity and enhanced the reliability of measurement.

Analyze Phase

In the Analyze phase, two tools were applied: bottleneck analysis and a fishbone (cause-and-effect) diagram. A bottleneck is any process step where flow is constrained, resulting in buildup of WIP. Figure 3 shows that operator 2 was identified as a bottleneck, where material accumulated due to higher cycle time. To address this, an additional operator was assigned to Step 2, balancing workload so that all cycle times aligned with the takt time of 15 seconds. The modified layout, illustrated in Figure 4, reduced total lead time to 57 seconds, enabling smoother flow and improved throughput.

	Start	Steps 1-2	Steps 3-4	Steps 5-6	Steps 8-9	Steps 10-11
No. of operators		Ω	ΩΩ	Ω	Ω	Ω
Cycle time (Seconds)		6.60	10.28	8	8.92	8.87
+ 4 seconds added for material handling						
Total		10.60	14.28	12	12.92	12.87
Rounded Total		11	14/2 = 7	12	13	13

Figure 4. Modified process flow with additional operator at Steps 3-4.

Next, Figure 5 shows the fishbone diagram that was developed to identify potential root causes of defects. Among the primary contributors were inaccurate and inconsistent folds. To address these issues, the Single Minute Exchange of Dies (SMED) technique was proposed. A simple metal die was designed to ensure consistency in the first folding step, as elaborated in the Improve phase.

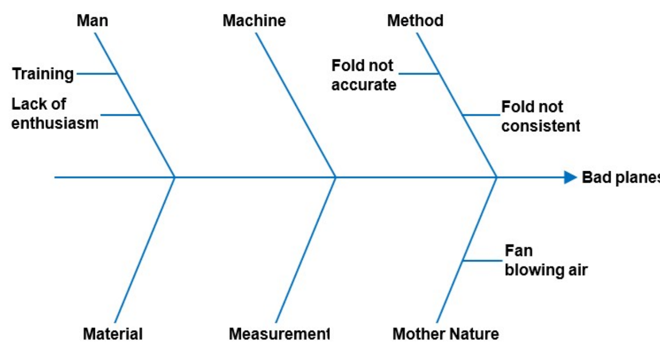

Figure 5. Fishbone diagram.

Improve Phase

The Improve phase focused on eliminating waste and reducing variation using lean tools such as push and pull production systems, kanban, SMED, FIFO (First In, First Out), and single-piece flow. Table 3 shows that a total of six 10-minute runs were conducted with the objective of achieving 40 defect-free planes.

- The first run, using batch production, produced only one good plane due to excess WIP.
- The second run, using push production, increased output but led to high WIP and defects.
- The third run, a pull system with 1-piece kanban, improved quality but resulted in minor idle time.
- The fourth run, with a 2-piece kanban, balanced flow and reduced idle time.
- The fifth run introduced SMED and FIFO, enabling Operator 1 to work efficiently without overproduction, yielding 39 good planes. A simple SMED technique of using a corner of a table with an elevated strip of wood was used.

Table 3. Lean principles applied in the Improve phase to reduce waste.

Lean principle applied	# Good planes	# Bad planes	Total	WIP
Batch production – size 5	1	6	7	27
Push production	18	13	31	10
Pull production – 1-piece kanban	22	9	31	6
Pull production – 2-piece kanban	26	5	31	4
Pull production – 2-piece kanban – SMED with FIFO	39	7	46	2
Pull production – 2-piece kanban – SMED with FIFO & QA visual inspection	40	0	40	0

Control Phase

The final run introduced a Quality Inspector (QA) for visual inspection and rework of defects, achieving 40 good planes with zero WIP. The WIP was zero because the first operator ceased operation when he could see the process nearing 10 minutes and enough work on the line to be processed in that time, demonstrating visual management and process synchronization. In the Control phase, statistical process control (SPC) tools were used to verify process stability. Figure 6 indicates that X-bar and R-charts were plotted for a critical dimension "lower wing height."

Figure 6. Lower wing height.

This lower wing height should ideally be one inch. This dimension was chosen as a critical dimension because it had been found previously to play a pivotal role in the stability of the airplane. This dimension alone significantly impacts the outcome whether the plane will be deemed a good or a bad plane. Figures 7 (X-chart) and 8 (R-chart) show control charts plotted for this critical dimension. Both charts indicated that the process was within statistical control limits, confirming that process improvements were sustainable.

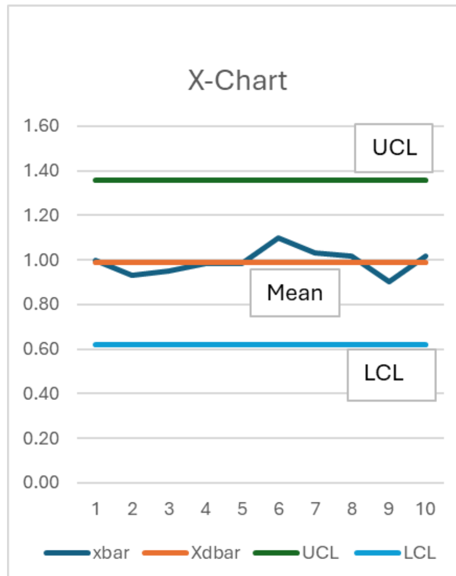

Figure 7. X-Chart.

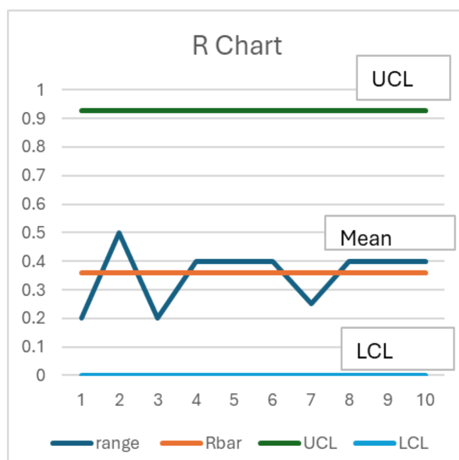

Figure 8. Range chart.

Conclusions

This classroom-based Lean Six Sigma project systematically demonstrated the DMAIC methodology through a hands-on paper airplane simulation. Students actively engaged in defining problems, measuring process performance, analyzing causes of variation, implementing lean tools to improve flow, and using SPC to verify process control. The integration of lean and Six Sigma tools—such as project chartering, Gemba walks, takt time analysis, kanban, SMED, FIFO, and control charts—allowed students to experience the full cycle of continuous improvement in a tangible, low-cost setting. Overall, the activity significantly enhanced student engagement, conceptual understanding, and practical problem-solving abilities. Furthermore, it motivated students to pursue formal Lean Six Sigma certifications at the Green Belt and Black Belt levels, bridging academic learning with industry-ready process improvement skills.

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Biography

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Engineering Technology Mission Creep Revisited: Examining Factors Associated with Drifts

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Abstract

Engineering technology bachelor's programs offer a critical link between theoretical engineering concepts and their real-world applications, equipping students with the skills to meet industry demands. Faculty in these programs should bring extensive industry experience alongside their academic responsibilities. Still, university policy requirements and the lack of engineering technology doctoral programs often make it difficult for faculty with engineering technology degrees to reach tenure and promotion, due to the absence of engineering technology doctorate degrees and to changing university policies that can alter the mission of engineering technology programs. This can also negatively affect faculty retention. In this study, the authors investigated the impact of tenure and promotion policies on faculty in four-year engineering technology programs, focusing on those accredited by the Association for Technology, Management, and Applied Engineering (ATMAE). Specifically, the authors explored whether university policies expand the mission creep associated with engineering technology programs, a subject that was investigated by Kenneth Rennels more than twenty years ago. In this current study, the authors utilized a recognized job satisfaction survey to identify concerns related to mission creep.

Introduction

In June, 2003, Professor Kenneth Rennels presented his findings on the dangers that university policies could pose to the mission of engineering technology (ET) programs in the U.S. (Rennels, 2003). The proceedings article examined two questions: "Will a doctorate degree be necessary for engineering technology faculty in the future for promotion and tenure in the university environment?" and "Will applied research be acceptable?" Rennels defined ET mission creep as moving ET programs more toward a traditional engineering mission. Much has changed over the 20 years since Rennels presented his research. Still, the same issue persists: university policies do not favor graduates of engineering technology disciplines becoming ranked faculty members (Hildebrant, Giltner & Payne, 2018). In fact, some universities advertise ET job postings with educational requirements for degrees that do not exist (Hildebrant et al., 2018). An example of this was an ET faculty position advertised at a public research university (ODU, 2025) that required a doctoral degree in a technology field that does not exist, according to the American Society of Engineering Education (ASEE) Index of Engineering Graduate Degrees (2025). This is not an isolated event, as other universities have advertised non-existent ET qualifications (Hildebrant et al., 2018). Another example was a position at a public, historically black 1890 land-grant university that only accepted theoretical engineering doctoral degrees for the position (KSU, 2025). The job postings demonstrate that the issues plaguing the ET discipline identified by Rennels (2003) still exist today.

The Southern Association of Colleges and Schools Commission on Colleges (SACSCOC), an accreditation organization that accredits higher education institutions, allows institutions to identify terminal degrees and requires only a master's degree, or 18 hours in the discipline, to teach in four-year programs (SACS, 2019). In addition to ET mission creep, other factors are affected by university policies, such as the presence of ET faculty with ET degrees and ET faculty retention. Engineering Technology, or applied engineering (CIP, 2020), equips students with the skills to apply engineering concepts vital to today's industry (Buchanan, 2018; Grebski & Grebski, 2019; Hildebrant et al., 2018). In areas such as automation, artificial intelligence, and cybersecurity, the ET discipline must remain relevant to drive industry into the future. In this current study, the authors examined the factors contributing to the ET mission creep identified by Rennels in his 2003 article and considered other implications of university policies on ET faculty, presenting data from faculty in four-year, ATMAE-accredited programs to address a gap in the literature on the subject. Furthermore, the authors examined the outcomes of academic program drift, including poor retention and job satisfaction (Dobrich & Fabac, 2021).

Literature Review

Professor Kenneth Rennels examined how ET programs deviated from their original focus on practical applications to a more theoretical approach due to university research and accreditation requirements (2003). At that time, Rennels presented evidence of hiring practices requiring higher credentials for ET faculty than in previous years. The study examined 229 ET faculty job postings from 100 institutions of which 37% required faculty to hold a PhD (Rennels, 2003). Rennels concluded in his study that university policies, not accreditation requirements, drove the increase in requirements to teach in ET programs (2003). He warned that increased requirements could make ET program missions more akin to theoretical engineering missions. He said it could lead to a situation in which university requirements dictate that ET faculty receive funded research that would push ET into an engineering mission, potentially ending ET programs at the university.

Kumar (2022), an Assistant Professor at California State University, identified a similar instance of mission creep, or academic drift, within the California State University (CSU) system. The author noted that the original mission designed the CSU system as a teaching-focused, undergraduate- and master's-level institution to adopt research university characteristics. The author found the changes to be incremental, consistent with Rennels' (2003) findings. The study concluded that mission creep can be determined by several factors, including misaligned incentives, poor managerial decisions based on a misunderstanding of CSU's mission, and poor employee job satisfaction. Another author, Longanecker (2008), researched mission creep among colleges and universities in the U.S. The author identified that it is generally the administrative and governing bodies that lack understanding of the academic, financial, and workforce implications of the college or its programs. The author noted that college administrations are not always grounded in a clear understanding of faculty qualifications, program requirements, or accreditation standards. He further argued that mission creep could be detrimental to public higher education systems and labeled it as a system-level failure of colleges.

An article in the Business Systems Research Journal investigated the relationship between employees' connections with their organizations' mission and job satisfaction (Dobrin & Fabac, 2021). The study found that an organization that strays from its mission correlates with lower job satisfaction. The authors also found that poor job satisfaction resulted from organizations that strayed from their mission or from employees who did not have a good understanding of it. This same confusion was said to affect university policies due to a misunderstanding of the ET discipline. This has plagued ET programs since their conception (Buchanan, 2018). Theoretical engineering programs are straightforward and align more with traditional university research programs. Generally, two-year programs are considered pre-engineering and are simply a transfer degree into a Bachelor of Engineering program (KCTCS, 2025). A graduate of a specific engineering program, such as electrical, mechanical, or similar, can continue their education into a PhD in their field (ASEE, 2025).

The ET discipline is much more complicated and generally does not align with other university research programs. A student can earn a two-year degree in ET and become a technician (BLS, 2023), while a graduate of a four-year ET degree generally receives employment as an engineer or a similar role (Land, 2012). Land recognized that accrediting agencies and educational institutions identified four-year ET graduates as technologists, distinguishing them from engineering graduates. Nevertheless, very few industries in the U.S. had positions for technologists. He also found that 70% of the companies he studied did not distinguish between engineering and ET graduates when hiring.

An example of the demand for ET programs can be found in the Kentucky Council for Postsecondary Education (CPE) 2020 study on manufacturing demands in the state, which projected the need for 3000 more engineers by 2029 (CPE, 2020). The study identified two degrees as the most in-demand in the state: manufacturing engineering technology and industrial engineering. The results showed that the industry in Kentucky recognized the importance of ET programs. Even though ET is in high demand, other factors confuse the discipline. One is that the U.S. Bureau of Labor Statistics does not recognize a four-year ET degree in its Occupational Handbook (BLS, 2023). The organization lists ET degrees under two-year technician degrees and includes four-year ET degrees alongside engineering degrees. The National Academy of Engineering (2017) identified another confusion within the National Center for Education Statistics (NCES) CIP codes, a federal standard to classify academic programs. NCES identifies theoretical engineering programs in CIP 14 and ET programs in CIP 15. The issue is that there is no separate designation for two- and four-year ET programs (CIP, 2020; NAE, 2017).

There are two accrediting bodies for ET programs in the U.S.: The Accreditation Board for Engineering and Technology, Engineering Accreditation Commission (ABET-ETAC), and the Association for Technology, Management, and Applied Engineering (ATMAE). A 2021 report from the ATMAE annual conference found that, among the more than 130 accredited bachelor's degree programs, only 8% of their faculty held an ET degree (Trends, 2022). This exemplifies the shift in the ET discipline that Rennels (2003) identified in his study.

Methodology

In this current study, the authors surveyed faculty using Google Forms from four-year, ATMAE-accredited ET programs. Due to differences in community college promotion policies compared to universities, the authors did not survey faculty from two-year, ATMAE-accredited ET programs. The participants were asked, "Does your university require a PhD for tenure and promotion?" This allowed the data to be aggregated into two categories, establishing dependent and independent variables. The study had to be revised before it was released to determine whether a perceived ET retention problem existed and whether there was a correlation between the two groups. The authors found that universities prefer not to release faculty retention data because it could give a negative outlook on the university, which could decrease student enrollments. The survey asked the faculty if there was a problem retaining ET faculty within their department. The study used Paul Spector's Job Satisfaction Survey (JSS, 2022) and the demographic questions to find statistical correlations between faculty satisfaction and university policies. The outcomes were also used to identify mission creep with the ET discipline. Paul Spector allowed the use of his instrument for non-commercial research purposes (Spector, 2023). The study population was faculty in ATMAE-accredited, four-year ET programs. At the time, ATMAE accredited 137 four-year programs throughout the U.S. (ATMAE, 2025). Using the G*Power 3.1 (Faul, Erdfelder, Lang & Buchner, 2007) analysis software to conduct an a priori power analysis, a minimum sample size of 52 was calculated with power = 0.80, effect = 0.5, and α = 0.05. The study used a larger effect size in order to detect a statistically significant association on the observed retention of ET faculty with a smaller sample size (Faul et al., 2007). The survey had 53 respondents from ET faculty in ATMAE-accredited programs.

Statistical Test

In this study, the authors used a chi-square 2 x 2 statistical test to determine whether a correlation existed between the two groups and the ET faculty's perceived retention, based on the first demographic question, "Does your university have a problem with retaining engineering technology faculty?" The test was selected because it compared two groups with dichotomous dependent variables (Newsom, 2024). Next, the authors took the overall results from the JSS and ran a Welch's t-test to determine whether job satisfaction differed between the two groups. The test was chosen because it is used in research to compare the means of two groups when the sample sizes are different, and the variances are unequal (Derrick & White, 2016). Minitab was used to run all the tests for the study. The software is a standard engineering statistical software used in manufacturing situations (Minitab, n.d.).

Survey Instrument

The JSS is a widely used instrument that measures nine facets of job satisfaction—pay, promotion, supervision, benefits, contingent rewards, operating conditions, coworkers, nature of work, and communication—consolidated into a 36-question Likert survey, making it well-suited for examining mission creep among engineering technology faculty. Mission creep at the faculty level appears as role ambiguity, role overload, and a misalignment between assigned duties and the original mission focused on teaching and industry. These conditions are reflected in key JSS facets: nature of work, operating conditions, supervision, and communication (Kumar, 2022). Thus, the JSS becomes a downstream indicator of institutional mission drift as experienced by faculty, even if not specifically named in policy or administrative language.

Cronbach's alpha overall score for the JSS index was 0.91, based on the total of the survey facets, with a sample of 2,870 (Spector, 1985). The survey has been validated across diverse occupational groups and cultural contexts, making it a reliable tool for academic research and applied organizational settings (Campos, Cunha & Oliveira, 2021). The JSS is frequently used in organizational psychology and management studies to inform decisions about workplace policies, employee engagement initiatives, and human resource practices. The JSS can provide valuable insight into whether a company or department is experiencing mission creep through its nine distinct facets (Campos et al., 2021).

Results

The authors surveyed faculty at ATMAE-accredited (n = 53) institutions in the U.S. using a stratified sampling method, offering the survey only to faculty of four-year programs. ATMAE staff distributed the survey to each college's administration to give to program faculty. Since universities did not want to release their faculty retention statistics, the study asked faculty whether they had problems retaining ET faculty within their departments. The authors found that 66% (n = 53) perceived that their university had a problem with retention of their ET faculty when divided into the two categories, 81% (n = 11) of the faculty from universities that accept a master's degree for tenure and promotion, and 63% (n = 42) of faculty from universities that required a PhD for tenure perceived a problem with ET faculty retention. A chi-square test was performed in Minitab to assess the significance of the observed relationship between the two groups. Table 1 shows that the chi-square test of independence found that X2 (1, n = 53) = 1.4271, p = 0.2322, Effect Size = 0.699, indicating no significant relationship between the two groups.

Table 1. Does your college have a problem with engineering technology faculty retention?

	Yes	No	Row Totals
Requires a PhD for tenure	27	16	43
Requires a Master's for tenure	9	2	11
Column Totals	36	18	54

Next, the authors examined the JSS scores across both groups to determine whether there was a statistical relationship between job satisfaction ratings. The average JSS scores for the faculty from universities that accepted a master's degree for tenure and promotion (M = 128.64, SD = 3.42) and the faculty from universities that required a PhD for tenure and promotion (M = 134.21, SD = 2.09) placed both groups as ambivalent about their job satisfaction (Spector, 2023). A Welch's t-test was performed in Minitab to determine whether the outcomes of the two groups were equal. Unlike a standard t-test, the Welch's t-test omits the assumption that two groups have equal variances; hence, statisticians recommend avoiding assumption checks using Welch's t-test (Delaire, Lakens & Ley, 2022; West, 2021). The results of the Minitab test indicated $t(11) = -0.41$, $p = 0.688$, suggesting no significant difference in job satisfaction between the two groups.

A closer look at the individual JSS survey segments with the most significant discrepancies revealed areas where the two groups differed. Table 2 presents the results for the nine individual sections of the JSS, including total satisfaction between the two groups and pay satisfaction scores in this study. According to the JSS score interpretation, any subscale score below 12 indicates dissatisfaction (JSS, 2022). Although there was not as much of a difference as in the nature-of-work outcome, there were other trends to note. One is that the group from universities that required a PhD for tenure and promotion had a higher promotion satisfaction rate than the group that accepted a master's degree for tenure. This could result from the fact that faculty from that group held PhD degrees. Outcomes from fringe benefits and contingent awards were also slightly higher among faculty from colleges that required a PhD.

Table 2. Paul Spector Job Satisfaction Results

Groups	No PhD Required	PhD Required
	n = 11	n = 42
Pay	10.45	11.9
Promotion	11.91	13.31
Supervision	17.45	17.95
Fringe Benefits	13.73	14.62
Contingent rewards	12.64	13.26
Total Satisfaction	128.64	134.21

Among the categories measured by the JSS, the most significant difference between the two faculty groups was found in satisfaction with the nature of their work. Faculty from colleges that accepted a master's degree as a terminal qualification reported the highest scores in this category, with a mean of 20.27, which fell within the "satisfied" range. In contrast, faculty from institutions that required a PhD for tenure and promotion reported a mean of 14.67 in the same category, reflecting an "ambivalent" interpretation of their satisfaction. These results align with Rennels's (2003) findings, which argued that institutions that require ET faculty to hold PhD degrees for tenure risk shifting their programs away from their applied mission. Rennels further suggested that, unless policies were revised to recognize the master's degree as a terminal credential, ET programs would increasingly resemble theoretical engineering programs, as faculty would lack degrees grounded in engineering technology.

A demographic question was also asked to determine if there might be a misunderstanding of the number of PhD degrees in ET offered in the U.S. Interestingly, 43% (n = 53) of the surveyed population believed there were more than five ET PhD programs in the U.S. According to the ASEE Index of Engineering Graduate Degrees (2025), the number of programs is much lower, suggesting confusion within the discipline. This is particularly surprising because all participants were from the ET discipline. This revealed a significant issue with a lack of education about the ET discipline.

Conclusions

The study revealed no significant difference in overall JSS scores between faculty from ATMAE-accredited ET programs who worked at universities that allowed a master's degree for tenure and promotion and those who worked at universities that required a PhD degree. It also revealed that both groups had problems retaining ET faculty in their programs. Several factors have shifted away from the original ET mission mentioned by Rennels. ATMAE found that only 8% of the faculty in ATMAE-accredited four-year ET programs held a degree in ET (Trends, 2022). The survey found that 79.3% of the surveyed faculty came from universities that required a PhD for tenure and promotion in ET programs, while Rennels found that only 33.6% of job postings required a PhD in his research, although there are very few PhD degrees in ET (ASEE, 2025). The research also found that faculty from universities that required a PhD had an "ambivalent" interpretation of the nature of work category, with a mean of 14.67, while faculty from colleges that accepted a master's degree had significantly higher satisfaction with their nature of work, with a mean of 20.27.

The outcome could be related to more theoretical engineers teaching in applied engineering (ET) programs. While theoretical engineers have successfully taught ET for years, differences in applications between research and practice may be driving the low satisfaction rate (Rennels, 2003). Future research should be conducted to verify this, as Dobrinic and Fabi (2021) found that low job satisfaction resulted from employee misunderstanding of organizational missions. This aligns with the study's finding that ET faculty overwhelmingly identified a perceived faculty retention problem within the ET discipline. All of the results are signs of ET mission creep that Rennels identified in his 2003 study. Lastly, most ET faculty surveyed were unaware that fewer than five PhD programs in ET are offered in the U.S. (ASEE, 2024). Accrediting agencies like ATMAE and ABET-ETAC must educate faculty and university administration on the importance of four-year ET programs and on the differences between ET and theoretical engineering.

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Donk Racing and STEM: An Exciting Informal Learning Setting

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Abstract

Donk racing, a division of the National Drag Racing Association (NDRA), is the newest and fastest-growing sector of racing in the U.S. and may serve as a compelling gateway to ignite interest in STEM among young minds. Young people are attending these races for entertainment but there could be a hidden educational component. "Donks" are big cars with big wheels that race on dragstrips and in the streets throughout the southern states of the U.S. A car is considered a Donk if it is a fifth-generation Chevy Impala or Caprice (1971-1976) equipped with at least 26-inch wheels, low-profile tires, and a lifted suspension to accommodate those wheels. A study to explore the relationship between Donk racing fans and STEM education was conducted by the authors.

The research attraction was prompted by the diverse fan base and use of applied engineering in an informal setting. People of color are noticeably absent from IndyCar, NASCAR, and Formula One events, as these sectors of racing were historically segregated and remain economically unaffordable for minorities in most instances. Conversely, Donk racing is affordable and dominated by African Americans, primarily in rural areas of southern states. The research question emerged: Do the fans in the stands realize they are watching applied engineering in an informal setting and how might this interest inform educational or career decisions? What attracts the younger fans to these racing events? Donk racing demonstrates the practical relevance of STEM education in a thrilling and captivating manner that may engage more underserved communities and underrepresented minorities.

Introduction

In this study, the authors explored the use of Donk racing, an often unknown or overlooked sector of drag racing, to attract more underrepresented minorities to Science, Technology, Engineering and Mathematics (STEM) fields of study. Donks, also known as high risers, because of the twenty-six-inch (at a minimum) wheels, became a trend in the 1990s in South Florida and now exist throughout the U.S. Big wheels, low-profile tires on any 1971-1976 full-sized Chevy Caprice or Impala, extensive chrome, customized paint colors, elaborate interiors, and other exterior embellishment command attention and often wonder. A recent article in Dragzine (Wagner, 2021) describes one Donk this way: "Under the hood is a Steve Morris-built 427 ci LS V-8 with an F3 Procharger that puts out 2200 hp to the flywheel on methanol."

"An FT1-built Reid-core Power Glide sends scads of torque to a Fab 9 rear that houses a set of 3.90 gears. Managing all that is the job of a custom triangulated four-link rear suspension, Afco adjustable coilovers and an anti-sway bar." One racing series sponsored by In and Out Customs, an auto restoration service in Charleston, S.C., covered ten months in 2022 in the states of Florida, Missouri, Texas, Mississippi, Tennessee, South Carolina, North Carolina, Maryland, Georgia, Louisiana, Nevada, and Indiana. The research team did not find any clear estimates of participant numbers but, in addition to a robust racing schedule and a weekly television program called *Donkmaster*, were able to firmly establish the Donk experience in popular culture. Figure 1 shows a picture of a classic Donk.

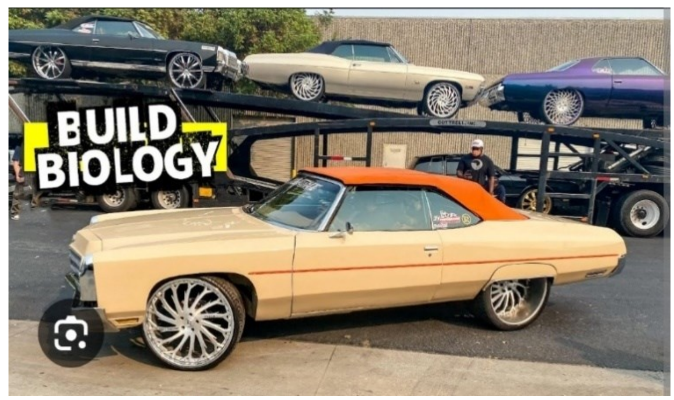

Figure 1. Donks built by In and Out Customs and Sage Thomas.

The lead author became interested in Donk racing during the COVID-19 lockdown after watching the television show *Donkmaster* on Vice TV. Like many during this period, the author engaged in binge-watching, but this program also sparked scholarly curiosity. Although *Donkmaster* can be considered a relatively low-budget reality show, it offered more than mere entertainment. Donk racing presented an opportunity to explore STEM in a unique context. The authors observed how Donk racing incorporated applied technology and engineering, although these aspects may not have been apparent to many spectators. This led to the idea that Donk racing could potentially serve as a platform to broaden participation in STEM. Over the last four decades, educators, industry leaders, and the federal government have sought to increase minority participation in STEM.

Scholars have approached diversifying STEM with several research initiatives, discovery practices for the classroom, gamification, formal learning advancements, and informal learning activities. After spending millions of dollars over the years, the needle has not moved in a sizable way, meaning that the number of underrepresented minorities pursuing STEM careers has not greatly increased in relation to the dollars and time spent.

If one considers standardized test scores in math and science, which are often used as assessment of competency, the numbers associated with the level of interest, proficiency, and college readiness are still lacking for children of color. In lower socio-economic groups, the typical public school lacks the resources to fully prepare students to succeed on standardized tests that are given throughout their academic career, starting with kindergarten and progressing through high school graduation. The debate centers around what is causing this lack of proficiency: Is it a lack of interest? Is it a lack of preparation? Is it a lack of test-taking skills? There are studies to support and refute each of these theories. However, without debate, it is known that individuals tend to study or become more committed to subjects and things they enjoy. Not only is enjoyment a means of attracting and retaining student attention, but cultural relevancy plays a huge part in commitment to mastery.

Donk racing is a culturally relevant way to connect STEM fields of study to African American communities. As described earlier, Donk racing has been seen as a unique sub-sector of drag racing often positioned in rural areas in the southern states of the U.S. with the urban vibe and high entertainment component. The entertainment component is notable; upon deeper examination one can see applied engineering in action. There would be no race cars without math and science, but this is not always obvious to the participants or the spectators. Simultaneously, there is a huge component of continuous improvement to win races and win money. All these processes lean on science in terms of aerodynamics, material science, physics, and chemistry.

The authors saw this obvious connection between Donk racing and STEM. The research question became, "Do spectators and participants see the obvious connection between drag racing and STEM?" In this case—not just racing technology, engineering, and math—you cannot build the car without science and math. Racers cannot improve their performance without science. So, if individuals are attracted to cars and going fast, are they attracted to math and science? This question became the point of discovery and the research questions that followed. A study was developed to explore these questions.

RQ #1: Is there an unconscious attraction to math and science that has not been recognized in the traditional classroom and testing models?

RQ#2: If some of the young people enjoyed this sport of Donk racing, will they acknowledge that they like math and science?

RQ# 3: At some point might the young racing fans consider careers in math, science, technology, or engineering?

In preparation for conducting the study of the attraction to Donk racing and science, technology, engineering, and math, the authors and team members prepared themselves by getting to know more about motor sports from thought leaders and the drivers of the quickly growing racing sector. During the first season of the study, 2022, the authors interviewed the Donkmaster, Sage Thomas. Interviewing the Donkmaster provided greater insight into how Donk racing, often called Big Wheel racing as well, started and has evolved over the last several years. They discussed what is included the sporting events and what the prospects of growth were at the time. Donk racing has several notable components to be explored. Along with being an obvious example of applied engineering, there are several business elements such as entrepreneurship, marketing, supply chain management, brand development, and social media influencing. In subsequent articles, the authors plan to address the business dynamics of Donk racing from an academic perspective. The focus of this current article is strictly on the connection to STEM education in an informal setting.

Literature Review

Motorsports is recognized as an exciting and captivating field that combines engineering, technology, and high-performance vehicles. In recent years, there has been a growing interest in exploring the connection between motorsports and STEM education. In this literary analysis, the authors examined the existing literature on the topic to shed light on the potential benefits and challenges of integrating motorsports into STEM education. The integration of motorsports and STEM education offers unique opportunities for students to engage in informal learning experiences. According to Hylton, P., & Russomanno, D. (2014), motorsports provide a compelling context for applying STEM concepts and principles. Students can explore various aspects of engineering, such as aerodynamics, materials science, and mechanical systems, through the lens of designing and optimizing race cars. The dynamic and fast-paced nature of motorsports also adds an element of excitement and real-world relevance to STEM learning.

Several studies have highlighted the positive impact of integrating motorsports into STEM education. For instance, Hylton (2010) conducted a case study in a high school setting and found that students who participated in a motorsports-based STEM program demonstrated increased motivation, improved problem-solving skills, and a deeper understanding of STEM concepts. The hands-on nature of working with race cars fostered experiential learning, leading to higher levels of engagement and knowledge retention among students. Furthermore, motorsports offers a platform to promote diversity and inclusion in STEM education. Traditional STEM fields have been ignored by underrepresented groups, including women and minorities. By incorporating motorsports, which has a diverse fan base, into STEM education, educators can create a more inclusive and accessible learning environment. As highlighted by

Jovanovic, Tomovic, Verma, Luetke, and Branch (2015), exposing students from diverse backgrounds to motorsports can spark their interest in STEM and inspire them to pursue careers in these fields.

However, there are challenges associated with integrating motorsports into STEM education. One of the primary concerns is the cost and accessibility of resources. Motorsports require specialized equipment, such as race cars, simulators, and testing facilities, that may be beyond the reach of many educational institutions. Additionally, the expertise needed to facilitate motorsports-based STEM programs may be limited, requiring partnerships with industry professionals and organizations. These challenges may be addressed by incorporating out-of-class experiences or informal learning time. Another challenge is the perception of motorsports as a male-dominated and exclusive domain. This may discourage female students from participating or limit their engagement in motorsports-related STEM activities. Addressing gender stereotypes and providing equal opportunities for all students is crucial to ensuring the success of motorsports-based STEM initiatives (Paraskevas, 2018).

In summary, the literature on motorsports and STEM education highlights the potential of integrating these two domains to enhance student learning and engagement. The hands-on, real-world applications of STEM principles in the context of motorsports can inspire students and promote diversity in STEM fields. However, challenges related to resource constraints and inclusiveness need to be addressed for effective implementation. Future research and collaborative efforts between educators, industry professionals, and policymakers should further explore the potential of motorsports as a vehicle for STEM education and its impact on students' academic and career trajectories. It should be noted that the previous literature, focused on STEM and motorsports, did not include Donk racing. It was focused of the more traditional sectors of motorsports.

The research frames for this project were culturally responsive (CR) and informal STEM learning (ISL), two educational domains that have proved effective in advancing interest and learning in STEM for underrepresented youth (Rubinson, 2016; Bottoms, Ciechanowski, Jones, de la Hoz & Fonseca, 2017). ISL, also called out-of-school time (OST) and free-choice learning (Falk & Dierking, 2010) profoundly influence long-term learning that includes science. Indeed, Falk and Dierking (2010) surmise that non-school resources, such as digital media, museums, zoos, aquariums, libraries, and family and community activities that are science related, "used by learners across their lifetimes from childhood onward actually account for the vast majority of Americans' science learning."

From a preponderance of studies, Falk and Dierking point to the findings of a major longitudinal study of urban and suburban Baltimore children that showed that, over a five-year period, reading performance for the two groups was equivalent. During the summer months of the study, however, urban children performed worse, leading Falk and Dierking to conclude that rather than giving children more school time instruction, as the study's authors had recommended, children would most benefit from more "quality" out-of-school time experiences.

To support such quality, informal (OST) STEM experiences (as with formal learning experiences) must be rigorous, affirming, validating, conversation rich, and authentically engaging with real-world problems and issues. And they must be connected to the children's lived experiences. That is, informal learning, especially for underrepresented youth, should be culturally responsive—a term whose prototypical origins go back to 1995 and the pioneering work of Ladson-Billings (1995) whose observations of effective classroom teachers of Black youth led to the term Culturally Relevant Pedagogy (CRP) and to three pillars or learning outcomes for children: academic success, cultural competence, and sociopolitical consciousness.

CRP is often used interchangeably with Culturally Relevant Teaching (CRT) (Gay, 2000). The former can be viewed as a philosophical system, an attitude, outlook, and way of interacting with children. This philosophy then informs curriculum development and pedagogical practice. CRT, in turn, emphasizes the importance of incorporating children's cultural identities into their educational settings with a pragmatic commitment to academic achievement. Ultimately, pedagogy must have philosophical underpinnings and, likewise, philosophy must shape pedagogical work. Both CRP and CRT are asset-based approaches that recognize and validate children's talents, skills, interests, concerns, and values. The goal of such child-centered pedagogies is to tap into these strengths to support the development of new skills and knowledge.

Methodology

This mixed-method field study was designed to take place on site at Donk races, which are typically all-day events on the weekends at rural racetracks in the southern states throughout the spring and summer months. The initial research team consisted of a professor of industrial technology with a background in manufacturing and a mechanic with three decades of experience as a subject matter expert. A graduate assistant was added to the team later to manage data and help with analysis. The team traveled to North Carolina, South Carolina, Maryland, Texas, Georgia, Alabama, and Florida to collect data over a two-season, eighteen-month period. A survey instrument was developed by using Google Forms with a QR code for easy access by participants in remote areas with minimal cell signal. Participants could scan the QR code to access the consent forms to participate in the study. Once the consent forms were completed, participants could answer the questions in the survey. When the survey was completed, participants were compensated with a T-shirt that was representative of racing and the car culture, apropos to the setting.

The questionnaire started by asking for brief demographics, such as age, gender, and ethnicity, and was then deidentified when the data were analyzed. The first question in the survey was, “Why you are attending a Donk race?” The authors sought to understand the initial attraction to Donk racing as reported by the spectators. The target age group of the participants among the spectators was youth ages 10-15. Data were collected from older spectators as well. However, this age group was targeted because literature has suggested this is the age group where most young people lose interest in math and science in school. These study questions might have lost interest in the classroom but still be of interest or attraction when evaluating real-world examples. What did people come to see at Donk races? Was it about the sport itself? Was it about cars? Where people drawn to Donk racing as a social event? This question about attraction was the first line of inquiry.

The next main question in the survey was about the participants’ favorite subjects in school. “What was their favorite subject in school? And what was their least favorite subject in school?” The follow-up question asked what they liked about each subject or what they did not like. Subsequent questions sought to connect the academic preferences directly to the foundational components of Donk racing and to college and career plans. It should be noted that African American youth, aged 10-15, were the target population of this study. However, data were collected on individuals of all ages. Some of the questions were flexible to reflect career choices and preparation instead of plans for college and career selection based on the age of the participant. The data from adults were analyzed separately from the youth in the sections on college plans and career selection.

The survey was comprised of approximately twenty questions depending on some of the responses participants stated. It took approximately five to ten minutes for each participant to complete the survey. Participants were compensated by receiving a free T-shirt with a picture of a 1953 Corvette on the front. The T-shirt was bright yellow with a blue car and garnered great attention at most racing venues. The design of the T-shirt also gave the research team an opportunity to connect with participants by sharing the story of the picture on the shirt. The 1953 Corvette was the first sports car built in America, and it was built in Flint, Michigan. This information about the shirt was interesting to many potential participants. Having a trivia fact about sports cars at events where data were collected proved fruitful. These T-shirts were not on the market or for sale. They were being given away as a “thank you” for participation in the survey. As the study progressed throughout the first season, relationships were built with drivers and eventually participants were able to use the T-shirts to receive autographs from thought leaders and winning drivers in Donk racing.

Data

Over 250 surveys were completed during an 18-month period. The 18 months comprised two race seasons—2022 and 2023. Data collection was not always easy or efficient. Because Donk racing is an outdoor sport, it is also weather dependent. There were several instances when the research team traveled to events and the event was rained out. Because of material science, these cars do not race in the rain. At one event, there was a rain delay that decreased the number of spectators and participants for that event. Collecting these data was expensive, when considering travel costs, but it was worth the investment because of the eventual responses gathered and the richness of the data. The charts and graphs of the following figures reflect some of the data that were collected. Besides basic demographic information, the first point of inquiry was the motivation to attend a Donk race. As stated earlier, the real attraction to these events can be questioned given the targeted population and locations. Why did people attend the Donk race? The graphs of Figures 2 and 3 provide visualizations of the responses to this initial question.

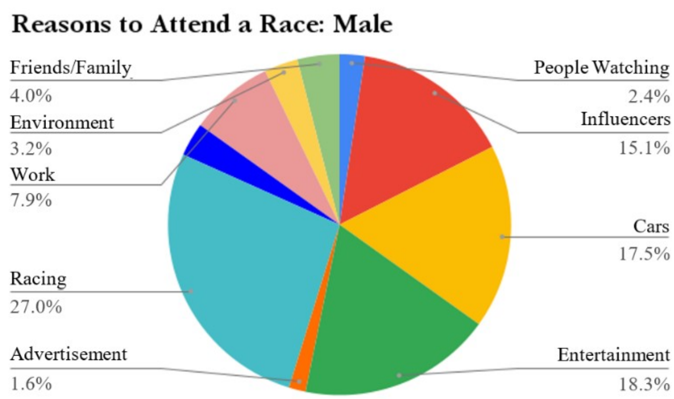

Figure 2. Why did male spectators and participants attend a Donk race?

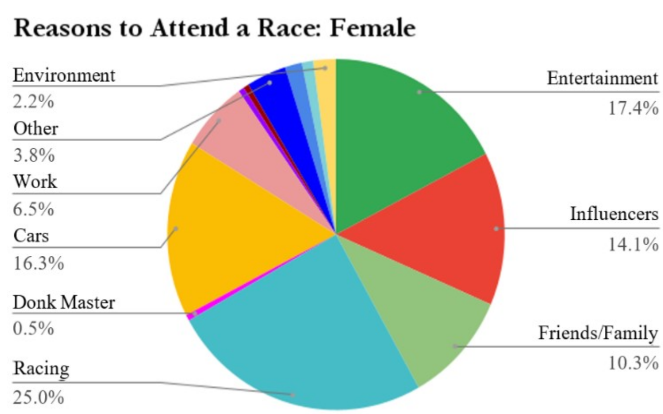

Figure 3. Why did female spectators and participants attend a Donk race?

After the data were collected, they were coded by major emerging themes. There were some outlying responses that were grouped with the closest related response or could be addressed individually if the rest of the survey responses warranted. As the charts above exhibit, people had numerous reasons for attending Donk races. The range of responses indicates that the motivation went far beyond the actual race itself, especially with the female participants. The male respondents listed racing (25%), cars (16.3%), and entertainment (17.4%) at the highest levels. These three categories represented 58.7%, over half of the males' responses to the question. It is safe to say, then, that most of the males were focused on the main events showing an interest in motorsports. The other noteworthy response was for the "influencers" at 14.3%. The reality that individuals will attend events because of influencers speaks to the power of social media and the changes in marking and business models.

With the female respondents, the highest number of responses were to be with friends and family (25%), racing (21%), entertainment (16.4%), and cars (14.5%). These numbers represent a social or cultural reason for attending along with appreciation for the actual event and participants. Interestingly, 10.9% of the females stated they came to see the Donkmaster. He has become a local celebrity and a major drawing card at similar events. Regardless of the motivation to attend, the participants were still witnessing informal STEM in action, whether they recognized it or not. The second question and related responses to be examined went to the core of this study: What is/was your favorite subject in school? The graphs of Figures 4 and 5 show the related responses. This is one of the most interesting or unexpected findings.

Favorite Subject in School: Male

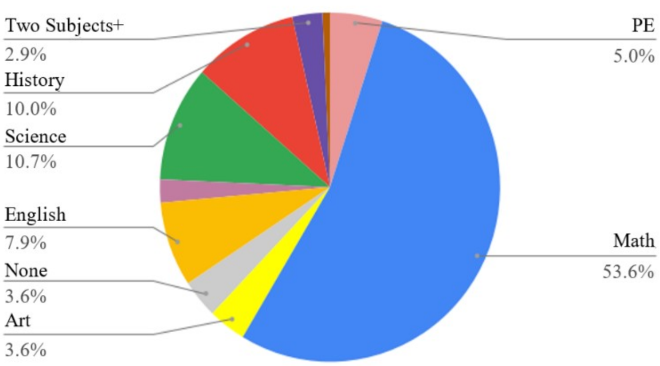

Figure 4. Representation of male respondents' favorite subject in school.

Analysis

Analysis of the data was conducted over the previous year. Each question on the survey was looked at individually and with respect to certain other questions. Data were stratified by age and gender to answer certain research questions proposed earlier. Approximately 10% of the surveys were incomplete and had to be removed from the analysis. Over 200 responses were still viable and used to answer initial research questions. Did these young people plan to go to college? Did they plan to pursue careers in science technology engineering, math or any other related field? If so, would it be a logical assumption and if not, why not?

Favorite subject in school: Females

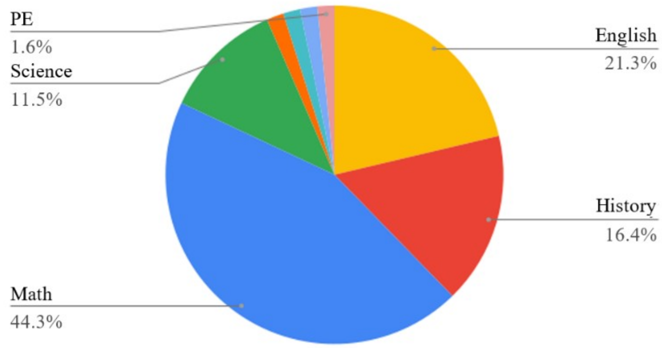

Figure 5. Representation of female respondents' favorite subject in school.

Findings

The first question that was answered in the survey was why individuals attended Donk races. The responses to this question covered a broad range of responses, including love for racing cars, attraction to speed, competitiveness, value, socialization opportunities, and attraction to cars in general. One of the reasons that participants attended Donk races was to support drivers and racing teams. Several participants mentioned community connectivity. This vast array of answers and multiple mentioning of community and team support speaks to evidence of cultural relevance. Donk racing (including big-rim racing) has a higher percentage of African American drivers, mechanics, and attendees than any other sector of racing. The entire event is filled with African Americans, a sprinkling of Hispanics, and occasional Caucasians. The music and vendor booths are representative of the racing theme in cultural alignment. NASCAR, IndyCar, and Formula One racing are typically unaffordable and inaccessible for many African Americans, especially in medium- and low-income communities. Surveying individuals at a Donk race provided access to large numbers of African American motorsports fans in various age groups at one time. This observation prompted questions about other sectors of racing, which will be explored in future studies.

The next major finding was the percentage of African American males that reported that math was their favorite subject in school. This is vital information, as decades of literature support the notion that math is a major barrier for African Americans completing engineering and technology curriculums at the college level. However, is the love or preference for math related to the possibility of becoming an engineer? Often minoritized and underserved communities are not aware of the academic and earning potential connected to STEM careers. Tangentially, this demographic is still highly representative of first-generation college students as well; that is, that the parents of the young men that acknowledged math as a favorite subject may be unaware of the potential connected with their interest. Interest in math leading to possible success in technology and engineering is a means for social mobility that is often unexplored in the African American community. The students that reported having math as a favorite subject reported an advanced array of career plans, which were often outside of science, engineering, or technology. The percentage that reported planning to go to college was less than 50%. The reason most often given for not planning to go to college was cost or affordability. This is a possible indicator of lack of information about scholarships, grants, or other means for funding a college education.

The third major finding from this study was the attraction of young females to math and science. Girls between the ages of 10 and 16 reported a preference for science as their favorite subject in school at over 40%. The interest in science is still noteworthy, as several other careers are built on knowledge in sciences. An attraction to science can also lead to careers in health fields such as nursing, pharmaceuticals, medicine and Health Administration. All these career paths can lead to social mobility. The most startling finding was the presence of illiteracy. At several locations, the research team encountered individuals that were unable to complete the survey because of literacy issues. Given the popularity of cell phones, technology, and social media, the research team assumed that individuals over the age of ten should all be readers. This was not always the case. The research team observed individuals requesting help from friends to read certain words. Some individuals declined to complete the survey when they realized they would have to read it and not be able answer questions verbally.

Conclusions

The decision to study Donk racing to gain a greater understanding about underrepresented minorities with respect to STEM education and career paths was a wise one. This study not only garnered rich details about education and career preferences, but also provided insight into culturally relevant informal learning settings. When the advertised races were canceled due to weather conditions, the research team took the opportunity to interview drivers and mechanics that were on site. The research team reported high instances of informal learning via peer mentorship with respect to the mechanics. After interviewing several mechanics, it was evident that most of them learned their skills from friends and family members, often without formal training. They continued to hone their skills often by trial and error to remain competitive.

This investment of time and dollars provided an opportunity to take a deep dive into Donk racing. As time progressed over the two years, the research team built numerous relationships with other motorsport participants, including an IndyCar team and motorcycle enthusiast. The connections made with these two professionals in these other motorsports led to developing corporate partnerships for the university. The opportunity to create class projects for students taught by the authors emerged on several occasions.

Plans for the Future

Additional data from the racing events has yet to be analyzed. There are also plans to collect data from other sectors of motorsports and, eventually, develop comparison datasets across various racing sectors.

Acknowledgements

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Biographies

E. SHIRL DONALDSON is an assistant professor at the University of Michigan-Flint. Dr. Donaldson has a career spanning over three decades as a seasoned professional and accomplished researcher. With a profound understanding of the intricacies of processes and systems critical for success, Dr. Donaldson's expertise is unparalleled. Holding a doctorate from Purdue University in industrial technology, Dr. Donaldson exemplifies academic excellence and scholarly rigor. Her extensive research portfolio encompasses a diverse array of topics, including Donk racing, STEM education, minority representation in higher education, graduate students in industrial management programs, rural STEM education, and more, demonstrating broad-ranging intellectual curiosity and an interdisciplinary approach. Moreover, Dr. Donaldson's commitment to community projects underscores dedication to fostering positive change beyond the confines of academia, exemplifying a role as a trailblazer and catalyst for societal impact. Dr. Donaldson may be reached at shirld@umich.edu

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