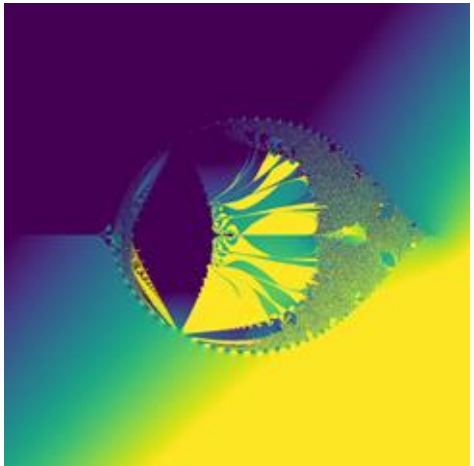
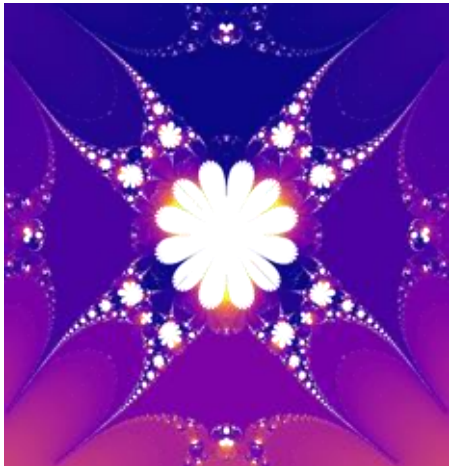
Running Undergraduate Research at a Smaller University

Kevin Sinclair and Cindy Schneider
Shenandoah University
April 25 2026





Who Are We

Dr. Kevin Sinclair - Large Scale Geometry

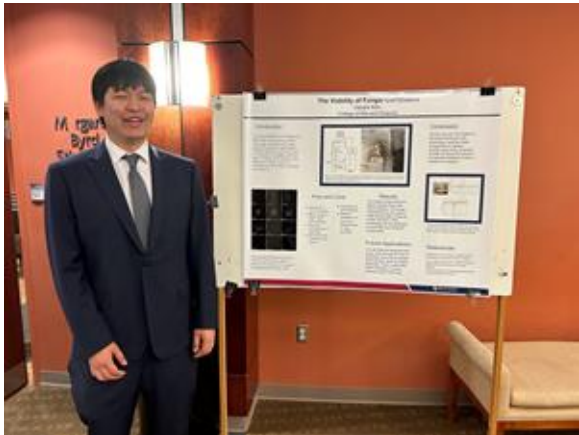
Dr. Cindy Schneider - Oriented Matroids

Shenandoah University

- 2,000 Undergraduate Students
- Math, Data Science, and Computer Science majors
- We graduate around 3-7 math majors a year

What Undergraduate Research do we do?

- All Math Majors have a year long capstone research class
- We compete at different research competitions
  - COMAP
  - Our Data Science and Engineering students shot a rocket off with NASA to gather data.
- We do cross disciplinary research
  - Environmental Studies
  - Chemistry
  - Biology
  - Public Health



What does our research class look like

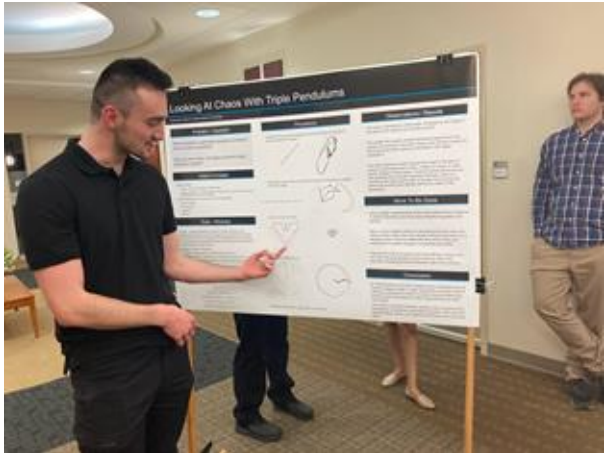
- Fall - 2 credits
  - Meet with library staff to make an Annotated bibliography
  - Meet with career services for professional development
  - Multiple speaking presentations with the research class in beamer
  - Literature Review at the end of the semester
- Spring - 2 credits
  - Poster presentations at SU and outside SU
  - Beamer presentations outside SU
  - Final Paper written as if it were for publication

Undergraduate Research Schedule

- Research Projects are Student Driven
  - Students pick the topic to research
  - Then, they find current sources and come up with a research question
  - If a student hits a dead end, then the instructor intervenes and helps guide them an interesting question.
- Students attend weekly meetings with their instructor
  - They report in what they did, what they found, what they will do next week
  - Mimics meetings they could have with a future boss or project lead.
  - Get students comfortable talking about their work with someone

Undergraduate Research Expectations

- End goal is to produce “something”
  - A new idea or result
  - Something similar to what was found and studied in a paper
  - Data was collected, methods were explored and nothing new was discovered
  - The journey is the destination - learn how to do research
    - The Productive Stuggle and Learning from Failure
- My Hidden goals
  - Students create a resume
  - Students create a linkedin
  - Students meet with the library and go over databases
  - Students forced to learn latex and beamer
  - Learn how to read/write a research paper

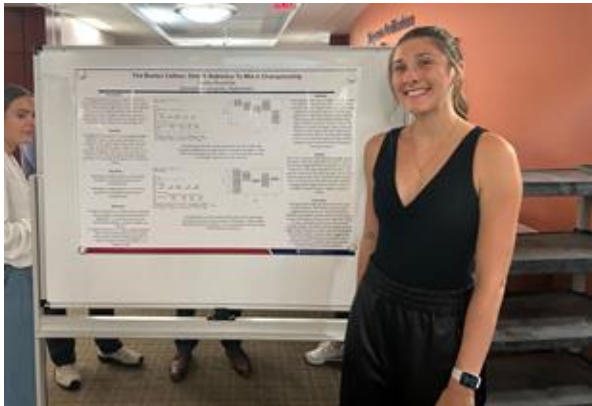


What Will Your students undergraduate research?

- Not peer reviewed publications
  - Can publish in a university journal
  - Some journals republish work if the students have completed it themselves
    - The Rose-Hulman Undergraduate Math Journal
- Exposure to Research Methods
  - Helps prepare for graduate school work or projects
  - Sense of ownership over a project
- Career and Professional Skills
  - Public Speaking opportunities
  - Professional resumes and online profiles
  - Builds a students ability to work on an open-ended project
- Introduction to modern mathematics
  - Learn something new outside of class
  - Learn what area they might be interested in after finishing college
- Resume buffers

What Will You Get From Undergraduate Research?

- Not peer reviewed publications
  - You still get things you can reference when you go for promotions
  - Creates “broader impacts” for students at your university
    - Can help with grants
- Connections with different offices at your university
  - Build a relationship with career services
  - Build a relationship with the people who purchase your research databases
  - Helps you make interdisciplinary connections
- Builds Communication Skills for Teaching
  - Get experience working as a leader with undergraduates
  - Get to teach material that goes beyond the classroom
  - Gives an opportunity to engage in active learning
- Resume buffers



Understanding Fractals Using Newton's Method

April Ulrich

Division of Applied Technology – College of Arts and Sciences

Introduction

We will discuss how both real and imaginary numbers create fractals; shapes whose roughness and fragmentation neither tend to vanish nor as one zooms in continually and examination is refined. In addition, we will analyze how fractals vary depending on modified versions of Newton's method as well as its rate of convergence. Finally, we will prove as to why certain functions in the complex plane either converge or diverge.

Goal or Aim

In analyzing Newton's Method, how does altering the original algorithm create entirely different fractals despite using the same function?

Purpose

- Learn about what fractals are and their behavior.
- Challenge our perceptions of numerical analysis and imaginary numbers.
- Provide entry points for individuals to recognize and appreciate the intertwined relationship between mathematical models and art.

Altered Newton's Method

Altered Newton's method is an algorithm derived and modified from Newton's method. This altered function entails finding where:

Xn+1 = xn f 0(xn), n 0

Results

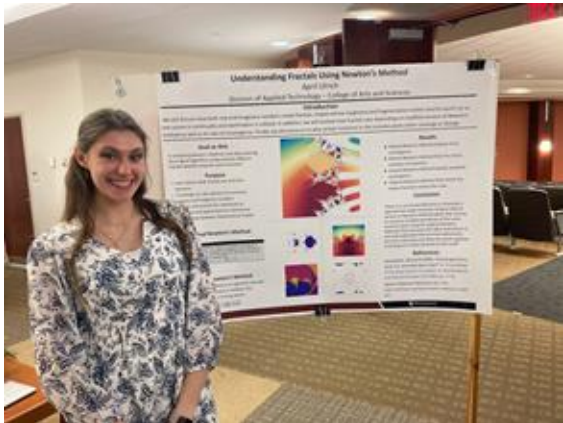
Altered Newton's Method displays linear convergence, whereas Newton's Method displays quadratic convergence.

Altered Newton's Method is in reality finding the critical numbers of a function; where the first derivative of a function crosses the x axis. Whereas the original Newton's Method is discovering where the original function crosses the x-axis.

Conclusion

There is a new found efficiency in choosing to approximate larger functions using an altered version of Newton's Method rather than having to compute multiple derivatives of the same function when using the original Newton's Method!! Not only does this allow individuals to see and understand that art and mathematics are one in the same; but they also work together in all aspects in what we know as life itself!!

References



The impact of salinity on *Aedes* mosquito oviposition and survival in Northern Virginia

By: Justus Whittington[1], Caleb Rivers-McCullough[2], Arika Chauglain[1], Zoe Star[1], Dr. Jeffery Bara[1], and Dr. Sinclair[2]
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Introduction and Hypothesis

Aedes mosquitoes use artificial containers filled with water to reproduce[1,2,3]. *Aedes japonicus* is a newly invasive species from Japan in the 1990s, *Aedes albopictus* was established in North America in the 1980s, and *Aedes aegypti* during the 15th century[4,5,6]. *Ae. albopictus* may be outcompeting *Ae. aegypti* in Virginia but the prevalence of *Ae. japonicus* is largely unknown[1,4]. *Ae. albopictus* found in Sri Lanka were found to have a salinity tolerance of 8-12ppt salinity[2]. *Ae. aegypti* mosquitoes show larval physiological tolerance-adaptations to salinity, such as changes to larval cuticles and an increase Sak expression in midgut[2,7]. Salinity-tolerance adaptations could result in changes to the mosquito disease vector and arboviral epidemiology, however the impact of salinity-tolerance adaptations is widely unknown in a world facing rising sea levels and increases in freshwater salinity[2,7,8,9].

We predicted that *Ae. albopictus* and *Ae. aegypti* would be the two most prevalent *Aedes* mosquitoes, with different species composition in urban and rural locations. *Aedes* oviposition will prefer lower salinity and increased salinity will decrease survival. We also predicted not gathering many Culex mosquitoes.

Methods

Larval collection sites were set up each with equal sized containers with 0ppt, 4ppt, 8ppt, and 12ppt salinity. Sites were checked daily for salinity, water level, and pupae. Pupae were brought to lab and incubated into adults at ambient temperature in the Ecology lab for species identification. *Ae. albopictus* were gathered from the field and a new generation were incubated in the Ecology lab. Adults were blood fed and eggs were collected onto wet paper towels. The egg-towels were added to water, larvae were generated and collected equally into 50mL containers with 0ppt, 4ppt, 8ppt, and 12ppt salinity at 37°C in Gregory lab for 3 replicates. Data analysis done with the Mathematics Department.

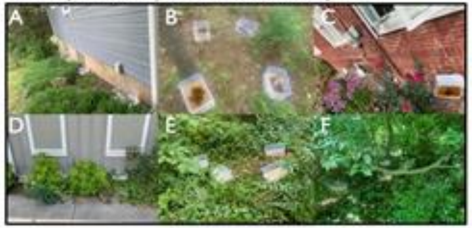

Figure 1. **Larval collection sites**. (A) Lake Holiday, (B) Lake Serine, (C) Downtown Winchester, (D) Shenandoah University, and Shawnee Springs (E) Red Rock (F) Near Bridge. The sites Lake Holiday (A) and Lake Serine (B) were located in residential subdivisions located north of Winchester up US Route 522. Red Rock and Near Bridge (C and D) were located a few minutes apart in Shawnee Springs park. The SU site (E) was located on campus and Downtown Winchester (F) was located in the urban downtown.

Results

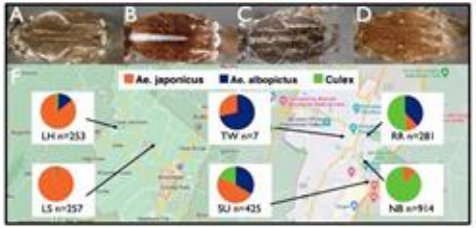

Figure 2. **Mosquito species diversity in Frederick County and Winchester**. Above are pictures of different mosquitoes (A) *Ae. aegypti* (B) *Ae. albopictus* (C) *Ae. japonicus* and (D) Culex remains which is representative of the broad class of Culex found. (F) The right portion of the map is Frederick County, and the left portion is Winchester. The rural sites, LH and LS, had predominately *Aedes japonicus*. The more urban sites, DW and SU, had more *Ae. albopictus* than the rural sites but still predominately *Ae. japonicus*. The DW site was oddly unproductive (n=7). SU had a more even species distribution. The sites in the park, SSRR and SSNB, had predominately Culex with a proportion of *Aedes*. The SSRR site had a specific localization of *Ae. albopictus* while SSNB had a localization of *Ae. japonicus*.

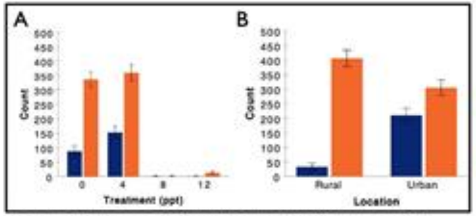

Figure 3. ***Aedes* oviposition by salinity and urbanization.** (A) *Ae. japonicus* and *Ae. albopictus* were found in higher amounts in the 0ppt and 4ppt containers than 8ppt and 12ppt. Of the *Aedes*, the 0ppt containers reared 425, 4ppt reared 513, 8ppt reared 2, and 12ppt reared 14. ANOVA and post hoc analysis revealed a significant difference between 0-4ppt (p=0.007), however other comparisons were NS (p>0.05). Of Culex mosquitoes, the 0ppt containers reared 128, 4ppt reared 320, 8ppt reared 94, and 12ppt reared 341 (data not shown). (B) The rural locations, LS and LH, had significantly less *Ae. albopictus* than the urban locations of SSNB, SSRR, SU, DW. Of Culex, 99.1% were found in urban bins (data not shown). Error bars represent 95% Confidence Interval.

Results Continued

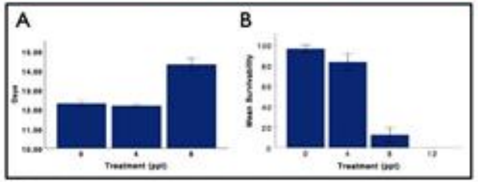

Figure 4. **Mosquito survival and development by salinity**. (A) *Ae. albopictus* larvae incubated in 0-4ppt salinity had similar development time, around 12 days. Larvae that developed in 8ppt took a few more days at around 14 days – however, there was a lower sample size due to lower survivorship. ANOVA and post hoc analysis revealed a NS difference between 0-4ppt (p=0.992) and a significant difference between 0-8ppt and 4-8ppt (both p<0.001). (B) *Ae. albopictus* larvae incubated in 0-4ppt salinity had very high survivorship however 8ppt had low survivorship and no mosquitoes survived in 12ppt. Graphed are the averages of the 3 replicates with error bars representing 1 standard error in both directions.

Conclusions and Future Directions

Aedes japonicus are an increasingly invasive mosquito in Northern Virginia, particularly in rural locations, with an ovipositional preference for lower salinities 0-4ppt. *Ae. albopictus* had a higher tolerance for lower salinities 0-4ppt. Increased salinity may result in an increased development time. There was a lack of *Ae. aegypti* or other *Aedes* species.

Investigate the biological changes of salinity-adaptations and their impact on disease vector quality. Establish and test more larval collection sites in Frederick County and Winchester. Investigate larval salinity tolerance between 4ppt and 8ppt.

Work Cited

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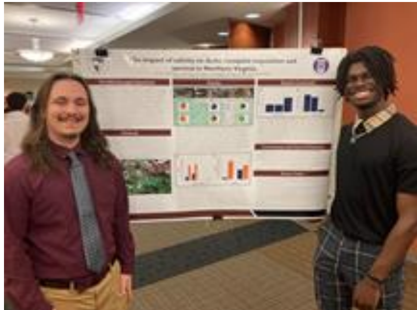


Analyzing Momentum in Tennis

Luis Urias Miranda
Shenandoah University

Goal

The goal of this project is to find variables with the greatest influence on the outcome of tennis matches. This can help competitive players determine which parts of a match to focus on to win matches through swings in momentum.

Hypothesis

- What control do players have over gaining and maintaining momentum in competitive sports?
- We predicted that individual moments, like serves, break points, and ends of games or sets carry the most significance in gaining momentum over an opponent during a match.

Methods

This was tested by creating several Convolutional Neural Networks (CNN) capable of predicting the next player to win a point, game, set, or match in the Men's Wimbledon 2023 tournament. Using the Explainable AI technique named Shapley Additive exPlanations (SHAP), each variable was given a significance value, or a measure of influence over the model's decisions, for each prediction done by the match predictor model (Lundberg & Lee, 2017). Variables with the greatest absolute influence for each match were collected.

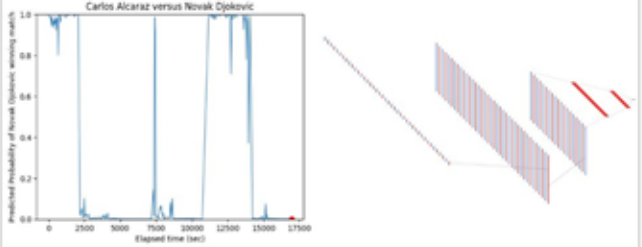
Dataset

The dataset contained information from each match of the Men's 2023 Wimbledon tournament from the round of 16 onwards, including player location, distance run, serves, returns, faults, break points, etc., with an entry for every point scored in each match.

Metrics

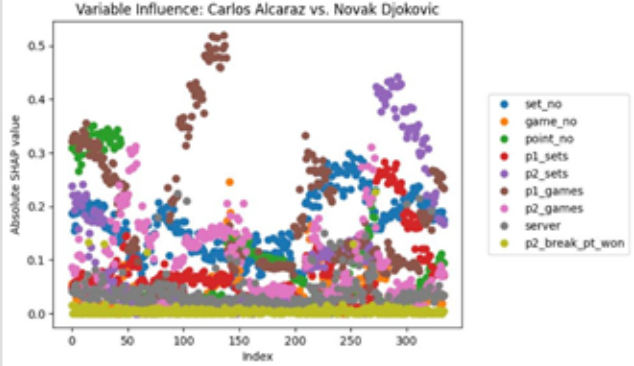
Match Predictor

Accuracy: 93.08%
AUC: 97.79%
Precision: 94.29%
Recall: 89.94%



Left: CNN prediction on the next player to win the match in *Alcaraz v. Djokovic*. Blue denotes the model's probability of Djokovic's win, and the winner of the match was Alcaraz.
Right: Structure of CNN for match prediction. The input layer convolves 42 input variables together into thirty-eight 128-length vectors which are subsequently pooled, convolved, and flattened to several dense layers leading to the output layer.

Results



Variables with SHAP values beyond threshold of ±0.2 in *Alcaraz v. Djokovic*. Outside of time-related variables (*set_no*, *game_no*, etc.), break points and the server had the greatest influence on the CNN's predictions.

Structure/Layers

- Convolution
- Maximum Pooling
- Convolution
- Dense (w/ 5% dropout)

Results

The most significant variables influencing match outcomes were the time elapsed in the match, who was serving, the serve speed, whether a fault was committed, and whether a player scored or missed a break point. These variables are in control of the players and could be areas to focus on in training. Other variables such as the number of games or sets passed also held significance in the model's decisions, but these are related to the elapsed time.

Conclusion

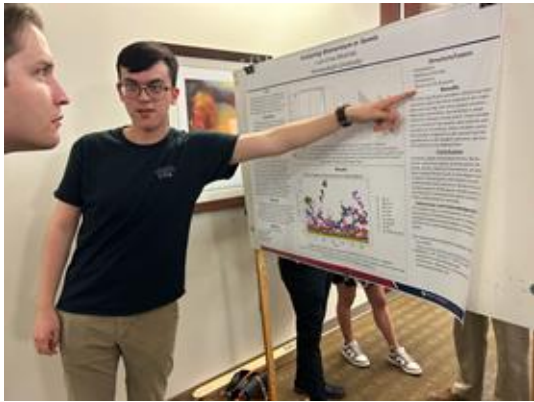
In tennis, player-controlled factors, like the server and serve speed, and key points, like break points, influence momentum, as well as time-related factors such as the elapsed time in a match. Knowing this information can help professionals and coaches in tennis to focus on certain aspects of the game. Further work into momentum in professional sports could help other professionals in winning.

References and Acknowledgements

This project was a submission for the 2024 Consortium of Mathematics and its APplications (COMAP) Mathematical Contest in Modeling (MCM) (*The mathematical contest in modeling* 2024).

The mathematical contest in modeling. COMAP, Inc (2024). https://www.comap.com/contests/mcm-icm

Lundberg, S. M., & Lee, S. I. (2017). A unified approach to interpreting model predictions. Advances in neural information processing systems, 30.



Using the Coupon collector Problem to analyze "gacha" games.

Royce Lorson
Shenandoah University

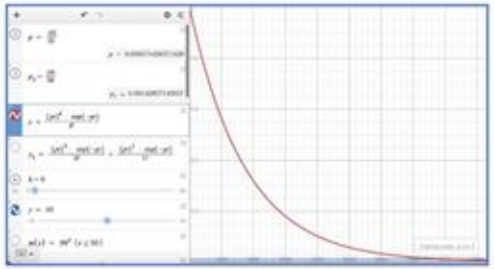


Figure 1: A K value of 1 resulted in a t of 8060

Introduction

Although the sample data used only affects people who might play video games, the coupon collector problem itself is applicable to many different fields. Since it can be used in a wide variety of situations, and can be used as both a reference, or used as a case for reasonable justification on some issues, the coupon collector problem is an important topic. However, since the problem does not see much use, to showcase it, I applied it to "gacha" games.

Purpose

- To find the expected number of times it would take to complete 5 full sets of characters from the game.

Methods

Figure 1: In the set of probabilities for the characters to be collected, we take the least likely to be obtained. Using this data, we graph the probability mass function for Poisson distributions. By selecting the K value carefully, we can find the intersection of this graph with a graphed confidence level to reveal the expected value t. In this case, we select k = 0 to simulate when 1 or more characters have been collected to estimate when we can be 99% sure we have 1 (or more) full sets.

Figure 2: Using formulas for the Basic Coupon Collector Problem, the mean, variance, and standard deviation were found by inputting the formula and data into a code written in R.

Figure 3: The setup is the same as in figure 1, however, we instead graph 5 k values k = 0,1,2,3,4. Doing so, we can estimate in the same fashion, when the expected value t is with 99% confidence for k of 5.

Figure 4: Another problem with a similar setup as figure 1, but in this case, in order to account for a game mechanic, only the probability has been modified. This is due to the game mechanic making rare characters easier to obtain.

```
n = 147
i = seq(1, n, by=1)
mu = n*sum(1/i)
mu

## [1] 818.9437

i = seq(1, (n - 1), by=1)
var = sum(1/(n-i))
var

## [1] 671.9437

sd = sqrt(var)
sd

## [1] 25.92188
```

Figure 2: Code to solve the Basic Coupon Collector Problem with results for mean variation, and standard deviation.

Results

Ultimately, as shown in figure 3, the research has shown that obtaining 5 full sets of characters in the game would require an expected value of 20,309 tries.

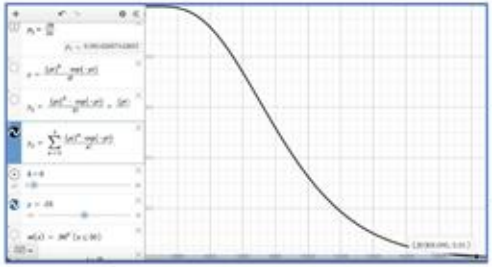


Figure 3: A K value of 5 resulted in a t of 20,309

Conclusion

Considering the value of every use of the "gacha" system is valued at about $ 1.43, getting 5 full sets would cost more than $ 29,000. Therefore, it is safe to conclude that it is not worth attempting.

References or Acknowledgements

@article{doumas2016coupon,
title={The coupon collector's problem revisited: generalizing the double Dixie cup problem of Newman and Shepp},
author={Doumas, Aristides V and Papanicolaou, Vassilis G},

@article{klaasen1994dixie,
title={Dixie cups: sampling with replacement from a finite population},
author={Klaasen, Chris AJ},

@article{myers2006some,
title={Some new aspects of the coupon collector's problem},
author={Myers, Amy N and Wilf, Herbert S},

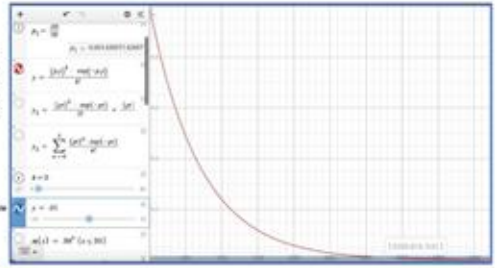
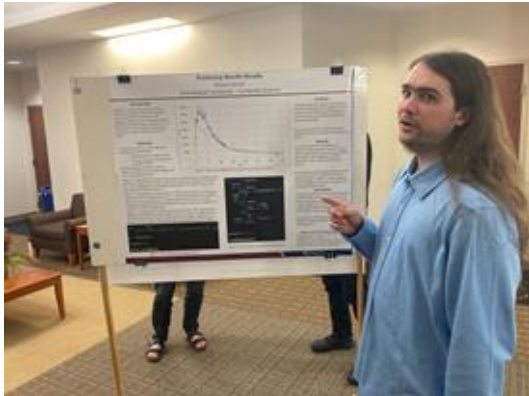


Figure 4: A K value of 1 resulted in a t of 3224



What I Learned My First Year As A Faculty Advisor

The Research Project:

- Collaborative Research with Environmental Sciences
- Kickoff included lectures, Q&A with expert in water quality and aquatic macroinvertebrates
- Data collection involved environmental science, math, data science, and computer science majors

What I Learned My First Year As A Faculty Advisor

Judgment Calls: Learning versus goal-orientation

- When to let them struggle, when to help
- Group dynamics: when to intervene

Promote opportunities to learn soft skills

- Present them with real-world complications
- Domain-specific knowledge matters
- Engage with aspects outside the immediate
  problem space
- Work with experts in other domains