ETHEL

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Cover Art

Preservation III, Preservation VII

About the Cover Art

I am a collector of the unwanted objects in the periphery of daily life, looking for opportunities to recycle them for new use and beauty. Every scrap of excess fabric and discarded paper holds the potential to briefly be something of notice before continuing on its path to refuse. In my work, I explore where the labels that define a person break down and look for gaps in the binaries of life. In the abstract forms of monotypes printed with refuse, a moment of pause appears. A figure falling in space, a branch of a gnarled tree, a topographic landscape, a glimpse of something not fully realized. The shapes in my prints are often non-specific, allowing for the viewer to take in and interpret the scene however they wish.

About the Artist

Caroline Wingerd is an interdisciplinary artist and printmaker currently based in North Carolina, pursuing a Bachelor of Fine Arts with a concentration in Print Media at the University of North Carolina at Charlotte. In the Spring of 2023, she also spent a semester studying print media and graphics at the Eugeniusz Geppert Academy of Fine Arts in Wrocław, Poland. Some of her exhibitions include Nutrient Rich at Goodyear Arts in Charlotte, NC, the *57th Annual Juried Student Exhibition* at UNC Charlotte, and *Expectations of Growth* at the Morgan Paper Making Conservatory in Cleveland, Ohio. She also curates shows of the work in the communities she exists in. In 2025 she curated To *Be Consumed* at Goodyear Arts and the first annual *Levine Scholars Gallery* in Charlotte, NC, and in 2023, she was a co-curator of *In Medias Res* at the ODA Gallery in Wrocław, Poland.

The ETHEL (Excellence. Transformation. Honor. Equity. Leadership.) Journal of Undergraduate Research, is a dynamic, interdisciplinary platform that highlights student research, fosters innovation, upholds academic integrity, promotes inclusivity, and helps shape the next generation of leaders.

Letter from the Editors

It is with great pleasure and pride that we present the first issue of ETHEL Journal of Undergraduate Research at The University of North Carolina at Charlotte. The journal is a culmination of months of dedication, intellectual curiosity, and a commitment to high-quality, compelling research from undergraduate researchers, faculty mentors, student reviewers, and Office of Undergraduate Research staff.

ETHEL Journal of Undergraduate Research, is a dynamic, interdisciplinary platform that highlights student research, fosters innovation, upholds academic integrity, promotes inclusivity, and helps shape the next generation of leaders. Emphasizing the core values of undergraduate research, ETHEL stands for Excellence, Transformation, Honor, Equity, and Leadership, and pays homage to UNC Charlotte's founder, Bonnie Ethel Cone. ETHEL is a student-run and student-edited journal which seeks to spotlight the incredible work of our undergraduate students and publish them for a greater audience to see. The articles presented in this issue cover a variety of pressing topics and represent Charlotte's disciplinary diversity, including work from biological sciences, computer science, social sciences, and humanities.

We would like to thank and congratulate each student whose work featured in this journal. Their diligent work has made this journal possible and is a testament to the academic excellence of the Charlotte community. Thank you to the Office of Undergraduate Research staff, ETHEL editorial board, faculty mentors, the writing resource center, and student reviewers who made the publication of the ETHEL possible. We hope you enjoy and are inspired by the work featured in this year's ETHEL issue.

Praneeta Sai Veluri
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Navigating the Integration of Artificial Intelligence and Surgery

Ishan Patel

Ishan Patel is projected to graduate in Spring 2025 with a major in Management Information Systems. His research interests are related to biology and microbiology, especially healthcare related research.

Abstract: Integrating artificial intelligence (AI) into surgery presents a promising avenue for enhancing diagnostic and therapeutic practices, yet challenges persist in advancing this technology in a surgical setting. Despite strides made in AI-based platforms for medical imaging, robot-assisted laparoscopic surgery, and anesthetic calculations, AI for surgery remains elusive due to limitations in existing optimization approaches and potential ethical issues that arise from utilizing such tools on patients. This literature review investigates the feasibility of utilizing AI to optimize surgery, particularly in aligning 3D images, assisting surgeons with breakthrough techniques, and highlighting certain areas of the body that surgeons have a hard time seeing while operating at the same time. Preliminary research reveals that leveraging an AI agent matches, and sometimes outperforms, current state-of-the-art methods in accuracy and robustness for aligning images in patient screenings and diagnoses. These findings highlight the potential of AI-driven image registration techniques to revolutionize medical imaging, offering insights into addressing long-standing challenges and paving the way for more effective utilization of AI in surgical settings. Additionally, it highlights the importance of continuous ethical considerations in the deployment of AI technologies in patient care, emphasizing the need for ongoing revisions to ethical codes to accommodate the evolving landscape of machine learning systems and technology. This review contributes to understanding the transformative impact of AI in a surgical environment while emphasizing the importance of ethical frameworks in harnessing its full potential.

Research Advisors: Dr. Mindy Adnot, Honors College; Dr. Srijan Das, College of Computing and Informatics, Professor Andrew Goff, Department of Biological Sciences

Keywords: Artificial intelligence, surgery, ethics, laparoscopic surgery, anesthetics, remote patient monitoring

Introduction

In recent years, the intersection of artificial intelligence (AI) and surgery has garnered significant attention and intrigue. The surge in AI applications across various sectors, coupled with the pressing demand for advancements in surgical practice, highlights the importance of exploring this emerging field. As AI technologies continue to evolve, their potential to revolutionize surgical decision-making, patient care, and operative techniques becomes increasingly evident (Mirnezami et al., 2018; Zhou et al., 2020).

Amidst this backdrop, a critical unresolved question emerges: How can AI be effectively integrated into the overwhelmed healthcare system to augment patient care through surgical procedures? How can it also navigate the ethical concerns that arise from autonomous patient care? The integration of AI into surgical workflows presents both opportunities and complexities (Mirnezami et al., 2018). While AI holds the promise of revolutionizing surgical decision-making, enhancing precision, and streamlining operative techniques, it also raises ethical dilemmas, regulatory hurdles, and concerns regarding human-AI collaboration (Rudzicz & Saqur, 2020). This inquiry goes beyond assessing the technological feasibility of AI in surgery. It also examines its impact on patient safety, healthcare delivery, and the evolving roles of surgeons and autonomous robotic systems.

Evidence from existing literature highlights the multifaceted applications of AI. Disciplinary fields such as computer science and medicine have explored the benefits and challenges of AI in surgery. While some research has been conducted on AI applications in healthcare, including medical imaging and diagnostic support, the specific inquiry into its integration within surgical practice remains relatively less studied (Liao et al., 2016). Existing literature offers insights into AI-driven advancements in surgical robotics in laparoscopic surgery (Biebl et al., 2021), anesthetic calculations (Dominikowski et al., 2021), patient monitoring (Shaik et al., 2023), and medical image analysis and overlap (Liao et al, 2016), highlighting the extensive applications of this technology.

While there is a small amount of research currently, the potential remains that AI will have a large impact on the healthcare industry. Most of these research studies have multiple follow-up questions that are important to answer in the future but show that AI can lead to a large breakthrough in bettering patient care. The main hurdle that most research studies encounter in this field is that patient testing is very limited due to certain ethical restrictions. Thus, the process of incorporating AI into surgery will be a slow transition before more techniques are introduced and researched (Mirnezami et al., 2018; Rudzicz et al., 2020).

This literature review attempts to explore the following aspects of AI's surgical revolution:

1. Considerations and challenges with AI's integration into healthcare
2. AI's potential uses for laparoscopic surgeries
3. Saving time in the operating room and emergency department
4. Automating anesthetic calculations and patient monitoring

To examine these questions, this literature review draws upon interdisciplinary sources from fields such as computer science, biomedical engineering, and surgical medicine. Given the rapid advancements in AI, newer research is particularly relevant. Therefore, most sources were selected from within the past five years, with some foundational or conceptual studies included from the last ten years. Peer-reviewed journals were prioritized, with articles sourced through the J. Murrey Atkins Library and databases such as PubMed and Web of Science. Additionally, relevant sources were identified by reviewing the reference sections of key articles, allowing for the discovery of studies that addressed specific aspects of AI's role in surgery. Selected studies were evaluated based on their credibility, empirical rigor, and contributions to ongoing discussions on AI in surgical applications. Preference was given to studies providing data, systematic reviews, and emerging trends to ensure a well-rounded investigation of AI's impact on surgical practice.

To provide a comprehensive analysis, this review is structured around four key areas where AI has significant potential to transform surgical practice, selected based on both practical implications and existing concerns surrounding AI integration. Ethical considerations were included because AI remains a controversial topic in many fields, especially in medicine. Addressing issues such as transparency, bias, and human-AI collaboration is essential for widespread adoption. A focus on laparoscopic surgery was chosen due to its reliance on cameras and other visual technologies, which present opportunities for AI-driven enhancements in visualization, surgical guidance, and automation. Time efficiency in the operating room and emergency departments was selected to explore AI's potential to streamline procedures and reduce stress on hospital systems and surgeons. These are critical factors in improving patient outcomes. Lastly, AI's role in anesthetic calculations and patient monitoring was examined because anesthesia involves complex dosage calculations, and AI's predictive capabilities may enhance both intraoperative and postoperative care. Within each subsection, studies were selected based on their contributions, ensuring that the review presents both theoretical insights and data-driven evaluations of AI's role in surgical advancements. This literature review aims to enhance understanding of AI's transformative potential in shaping the future of surgical care and patient treatment, while highlighting considerations that need to be taken before AI is fully integrated into healthcare.

Key Considerations and Challenges with AI's Integration into Healthcare

Prior to the complete integration of AI in healthcare, it is important to remember that there are many shortcomings in AI algorithms and ethical considerations that need to be addressed. The first challenge is that many studies that are currently utilizing AI have been published on preprint servers without being submitted to peer-reviewed journals. These studies often lack randomized controlled trials (RCTs) of AI systems but rather use small, prospective studies. Randomized controlled trials minimize bias and provide a strong correlation between interventions and outcomes. Medical professionals mainly trust peer-reviewed journals with RCT, so in the future, more trials need to be conducted using this method (Kelly et al., 2019).

Another challenge that exists with AI is the potential for algorithmic bias. AI systems are trained on sets of data, but if these data sets are limited to potential groups of people, patient diagnosis could be affected. In the healthcare field, many groups are already disadvantaged by factors such as race, gender, and socioeconomic background. If AI algorithms are trained off of biased data, it makes it harder to diagnose these patients on an equal level compared to patients who have more data for their background. One study found that hospital mortality prediction algorithms have varying levels of accuracy based on ethnicity (Kelly et al., 2019). AI algorithms also tend to correlate unrelated information to their diagnosis. Another study showed that an algorithm had a higher chance of falsely classifying a skin lesion as malignant if the image had a ruler in it. This was because the model was trained on images where many cancerous lesion pictures also contained a ruler within the image (Kelly et al., 2019). These discrepancies within AI algorithms need to be addressed before they can be fully utilized by doctors and surgeons for patient care.

Patient medical records and medical scans are sensitive information that warrants careful handling. If this information is stored in an AI-based algorithm, there can be potential data breaches that can leak patient

information (Rudzicz et al., 2020). Many attempts have been made to de-identify patients from their data. The problem persists that algorithms can re-identify individuals and match their data with their records from as little as 3 data points (Crigger et al., 2019). Medical scans can even be altered in malicious ways which can alter the algorithms of AI systems. An AI algorithm misdiagnosed an image of benign moles as malignant when the picture was rotated (Kelly et al., 2019). Something as simple as photo alterations could create trouble in patient care when a diagnosis is simply based on these algorithms alone.

It is important to find the balance between maintaining human oversight as well as creating ethical rules in place for this evolving landscape. Before this technology is deployed into patient care, AI needs to be able to promote the quality of care without creating disruptions. When AI models make predictions, it is also important to explain how those algorithms came to that conclusion to allow for more trust between physicians and AI. This technology should be seen as an additional tool to treat patients rather than a replacement for doctors, so this level of comfort should be sought after. Although many parts of AI may cause concern, many promising innovations will help surgeons treat their patients.

Using AI in Laparoscopic Surgeries

AI is gradually gathering more information on human anatomies and how surgical techniques are completed, with its capabilities expanding beyond current models. As more and more information is added into AI algorithms, the newer AI models will have more accurate information and data sets. With the ability to assist in surgical decision-making, one part of the body has been getting tested more frequently using AI decision support systems. For the gastrointestinal (GI) system practices, personalized treatment decisions are being generated through AI. One such example of personalized treatment involves artificial intelligence analyzing a patient's genetic sequence to figure out drug and gene-specific interactions. These relationships are utilized to minimize the side effects of pharmaceutical drugs. Generated decisions are then paired with the knowledge that surgeons already have to allow for the best decision-making (Mirnezami et al., 2018). The newest method of GI surgery is laparoscopic surgery, or surgery done using small incisions while viewing inside the body using a camera. Laparoscopic surgery as a whole is important, as it is minimally invasive, reducing blood loss during operations and pain post-procedure (Biebl et al., 2021). This reduction in complications and pain allows patients to recover more quickly while requiring fewer medications.

Before AI can be used in surgery, it has to be trained on the material it is learning using video analysis. Surgeons use laparoscopic videos of surgeries for training, but the process is hindered by the need for a human to review the footage and manually create educational annotations. This process is time-consuming, so machine-based AI can be used to streamline this process by analyzing the videos (Mirnezami et al., 2018). Videos of laparoscopic colorectal surgery (LCRS) were used to evaluate the accuracy of automatic recognition of the body using AI. In this research trial, 300 surgical videos were used, coming out to over 82 million frames being analyzed and annotated by AI. 80% of the frames were being used for the training dataset and the other 20% were used as a testing dataset. To analyze the frames, researchers used a convolution neural network (CNN), which is an AI model. The overall accuracy of this automated surgical analysis was 81%, which left some room for improvement but demonstrated an optimistic outlook for streamlining this process (Kitaguchi et al., 2020). One potential drawback that was mentioned earlier is algorithmic bias. This complication can potentially occur within this AI model that would negatively affect the accuracy of the model.

In order to apply this information to another project, a study was completed where an AI model called Eureka was developed to separate nerves in the GI system visually. The AI model used the same training videos that surgeons use as an educational tool for laparoscopic colorectal surgery (Ryu et al., 2024). This training model was used in colorectal cancer patient videos, where the nerves of patients are important anatomical landmarks that help surgeons see where to dissect. If a surgeon was untrained and caused nerve damage to this area by accident, it could lead to catastrophic issues such as urinary and/or sexual dysfunction (Ryu et al., 2024). After the results from the study were collected, it showed that the total mesorectal excision (TME) was safely performed by the surgical trainees with the help of AI navigation, with no postoperative complications occurring. When the trainees couldn't recognize the hypogastric nerves or the lumbar splanchnic nerves, the AI model aided in anatomical recognition in all cases. However, in recognizing the pelvic visceral nerves, the AI model only aided the trainees 25% of the time (Ryu et al., 2023). This research study helps to highlight the importance of AI in assisting in minimally invasive procedures, as there is less risk to patients and it has a high ceiling for improvement.

Using AI to Save Time During Operations and in the Emergency Department

Currently, during operations, surgeons require complex hand-eye coordination skills to look away from the surgical field to verify the position of the navigated instrument position on a monitor (Siemionow et al., 2020). This causes a high learning curve to be established for new surgeons, which removes time from actually learning and performing the operation. The movement of looking back and forth between a monitor and the patient also increases the amount of time in the operating room. A cross-sectional analysis was completed to see how much it costs a California hospital for operating room time. The results from the 2014 study showed that the average cost of OR time is \$36 to \$37 per minute, with around \$20 being direct costs, \$13 to \$14 attributing to wages and benefits, and the other \$3 coming from surgical supplies (Chu et al., 2022). By removing this unnecessary complexity of constantly looking at a monitor during the procedure, the duration of the operation will decrease. This saves money in multiple aspects, including anesthetic costs, and will eventually lead to lower medical bills for patients (Chu et al., 2022).

One way to fix this issue is by utilizing medical image registration, where two or more images are aligned. A research trial was created in 2016 that utilized an abdominal CT scan and a cardiac CT scan, and the goal was to see if AI could outperform human performance when aligning the medical images onto the patients. In both examples, the artificial intelligence agent outperformed current methods by a large margin, both in accuracy and robustness (Liao et al., 2016). Augmented reality is the new way to align medical scans. An augmented reality and artificial intelligence (ARAI)-assisted surgical navigation system was tested in a research trial to assess its accuracy and feasibility (Siemionow et al., 2020). ARAI creates a display system that hovers over a surgical field, projecting

3D medical images that correspond with the patient's anatomy. ARAI's navigation probes were tested in 4 cadaveric spines, and the probes were correctly placed in all trials (Siemionow et al., 2020). This shows how the augmented reality virtual overlay accurately corresponded to the 3D-generated image using AI in all tests.

Emergency departments are also areas where managing patient care using AI can shorten wait times. In most cases, patients wait for longer periods, while the actual diagnosis and treatment take a much shorter amount of time (Li et al., 2021). A study was conducted in China in which a natural language processing model (NLP) was created based on deep learning to extract clinical information from electronic medical records. Then, an AI algorithm was built based on the extracted information, which was called XIAO YI. This algorithm could take the information given by patients and determine the corresponding examination or test items that were needed based on that patient's current health problem. In this study, waiting time was defined as the time from registration to preparation for the imaging examination or lab test. Utilizing XIAO YI led to a reduction in patient wait times from 2 hours to 0.38 hours at Shanghai Children's Medical Center (Li et al., 2021). Ultimately, this allows for more patients to cycle through the emergency department, creating space for patients with more life-threatening issues.

Automating Anesthetic Dosage:

Calculations and Patient Monitoring

Another way to reduce time spent in the operating room is by automating anesthetic dosing, which streamlines a process that would otherwise require continuous manual adjustments by anesthesiologists, potentially saving crucial minutes during surgery. An experiment was completed that automated anesthetic inhalation for patients in order to reduce human errors. Some other benefits of automating this process include increased safety for patients, reduced costs, and less environmental pollution that is released from the process. This procedure was done under the supervision of an anesthesiologist during a laparoscopic operation, where the release of desflurane (anesthetic gas) could be controlled automatically. Currently, anesthesia machines have a monitor to analyze amounts of inhaled anesthetic gas and oxygen during inhalation and exhalation (Dominikowski et al., 2021). In this research study, Simulink software was used to build intelligent control systems using C language in programming, and AI was used to control the concentration of desflurane released. There were rules set by an anesthesiologist to make sure the concentration didn't stray outside of the optimal range. The results of this study showed that the algorithm generated the desired value of anesthetic concentration. One limitation of this study was that there wasn't a specific accuracy given on how often this value was generated, but the study did mention that the experiment should be implemented again using different anesthetic situations and gasses (Dominikowski et al., 2021).

During this experiment, the patient's heart rate (HR) and mean arterial pressure (MAP) were constantly measured. The rules set by the anesthesiologist are decided based on what should be done in case of a change in HR or MAP. The AI system simply reads the HR and MAP and automatically sets the desflurane concentration based on what the anesthesiologist determined earlier (Dominikowski et al., 2021). If AI can be used to read vital signs for anesthetic concentrations, then it should be able to continuously monitor patients in the operating room and even in in-patient situations. A literature review was completed that showed AI and machine learning can be used to monitor and even predict vitals in a similar way (Shaik et al., 2023). This can be applied to remote patient monitoring (RPM), where the health of a patient can be analyzed and predicted even while they are at home. Patients with chronic illnesses or elderly patients at remote locations can still be monitored to make sure their condition doesn't suddenly deteriorate. This application of AI will help to reduce the patient load in hospitals that still use manual monitoring of patient vitals, especially in rural locations (Shaik et al., 2023).

Unfortunately, there are also many challenges that come with RPM. Patient privacy and the uncertainty of how fast a patient's condition can change can sometimes not be predicted. This means AI should still be supplemented with direct physician supervision rather than being fully autonomous, and certain rules and regulations need to be set on how much a patient's information can be used for AI learning and monitoring (Shaik et al., 2023; Rudzicz et al., 2020).

Conclusion

Through this literature review, the exploration of the many benefits of using AI in surgery and patient care shines brightly. However, there are many challenges that also exist. Ethical issues such as privacy and autonomous control during surgery can be a tough hurdle to cross and require a slow and gradual change in the surgical setting and patient approval (Rudzicz et al., 2020). Many of these research studies had minimal live patient trials, which is very difficult to approve for testing. Another setback is that current AI algorithms aren't as accurate as physicians and can contain algorithmic biases that affect how patients are diagnosed. Patients and physicians will need clarity on how AI makes decisions in a medical environment before it can be fully integrated into healthcare.

After researching the applications of AI in surgery, the ability to integrate this technology into healthcare is more efficient and effective than ever before. AI's versatility extends to various areas within the healthcare industry, including the recognition of medical scans and their visual application over other surfaces. Augmented reality facilitates the alignment of scans over patients, streamlining surgical procedures and reducing time spent in the operating room. Moreover, AI can enhance laparoscopic surgery by analyzing videos and assisting in the identification and separation of nerves in the gastrointestinal system.

The benefits of AI extend beyond the operating room, with both image alignment and laparoscopic assistance contributing to shorter recovery times for patients. As surgeons complete tasks more rapidly, hospitals can accommodate more patients, addressing challenges such as overcrowded emergency rooms. Additionally, AI plays a crucial role in monitoring patient vitals and status, automating processes such as the adjustment of anesthetic gas levels based on heart rate and arterial pressure. This not only reduces the burden on hospitals but also enables remote patient monitoring and early detection of potential movement disorders or psychological disorders. These advancements represent a significant step forward in improving patient outcomes and streamlining healthcare processes. More research is required in this rapidly expansive industry, where the potential to improve patient care is endless (Mirnezami et al., 2018; Zhou et al., 2020). Once more research is completed, we will likely see the integration of AI to assist surgeons in operating and treating patients in a day-to-day setting.

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Scaling Art Classification Models: Enhancing Binary Classifiers and Tackling the Challenge of AI-Generated Art

Brendan Gorman

Brendan Gorman is projected to graduate in Spring 2025 with a major in Computer Science. His research interests are related to computer vision, AI, cybersecurity, and machine learning.

Abstract: This paper discusses the creation of an AI-based binary classification model that can efficiently classify artwork by artists, with two categories building on previous research in the area. The research topic here is to streamline current multi-classification models by using a binary classifier in assessing its performance compared to conventional multi-classification systems with multiple categories and artists simultaneously. Deep learning methods, specifically ResNet-101, were employed to distinguish between non-Monet and Monet paintings in the first study, and between Vincent van Gogh and non-van Gogh paintings in the second. The paper also discusses the implications of Artificial Intelligence (AI)-generated pieces of art, briefly delving into the difficulty of identifying if artworks are genuine or not to a computing system. The results show that it is possible to develop a theoretical multi-classifier through the fusion of various binary classifiers, thereby creating an efficient and scalable approach for handling large datasets and many artists. Nonetheless, whereas binary classification proves to be effective for traditional art with respect to accuracy, it cannot differentiate AI paintings imitating artists, thereby representing the limitation of the method. The paper concludes by emphasizing the potential for further advancements in art classification, particularly considering the growing impact of AI-generated artworks.

Research Advisors: Todd Dobbs, College of Computing and Informatics

Key Words: Binary classification, AI-generated art, art authentication, ResNet-101, scalability, Money paintings

Introduction

In recent years, the art world has faced unprecedented challenges in authentication and verification, particularly with the rise of sophisticated forgeries and AI-generated artwork. Thomas Hoving, former director of the Metropolitan Museum of Art, estimated that at least 50,000 pieces in circulation were inauthentic. In his book False Impressions, he famously stated, "I almost believe that there are as many bogus works as genuine ones" [5]. This sentiment underscores the growing limitations of traditional authentication methods, which rely heavily on expert analysis and provenance documents. In an era where both human forgers and artificial intelligence can create remarkably convincing replicas, these conventional approaches are no longer sufficient. As a result, museums, collectors, and researchers are increasingly turning to scientific techniques and machine learning models to enhance the accuracy of authentication.

In light of these developments, deep learning classification systems have arisen as a potentially worthwhile response to the need for art authentication. While stable analytical capabilities are provided by such models, they also present profound challenges. Recent research indicates that distributed deep learning models suffer from serious issues of computational complexity as well as scalability, especially in multi-graphical user interface setups. Evaluation results indicate considerable variation in the scalability of these frameworks, and the need for load balancing for parallel distributed deep learning [6]. To put it simply, these models require significant computational resources, and their efficiency varies depending on how well the workload is distributed across multiple GPUs. Deep learning frameworks such as TensorFlow, MXNet, and Chainer offer numerous primitive elements required for effective neural network structure creation for a variety of applications, such as computer vision, speech recognition, and natural language processing. These software tools are essential to help build and train models by providing functions for data processing, optimization, and efficient computation. Nonetheless, the performance of the deep learning frameworks at execution time is considerably inconsistent even when training the same deep network models on the same GPUs [6]. Although deep learning models such as deep convolutional neural networks (DCNNs) and ResNet have been promising for art classification, they need a lot of fine-tuning and computational power to attain high accuracy. The pre-trained DCNN demonstrates how fine-tuning DCNNs on large-scale artistic collections considerably enhances classification performance, enabling the networks to learn new selective attention mechanisms over the images [6]. Furthermore, this demonstrates that DCNNs that have been fine-tuned on a large artwork dataset classify cultural heritage objects from another dataset better than the same architectures pre-trained solely on the ImageNet dataset [9].

This research proposes a new approach using binary classification frameworks to overcome such challenges. By focusing exclusively on binary classification, it will seek to build a more efficient and less complex system that can seamlessly adapt to a range of artists while maintaining high accuracy. This work extends current work in artwork authentication [2] and introduces new work in model architectures and training experiments involving AI artworks.

Motivations and Research Objectives

The increasing prevalence of artwork generated through artificial intelligence, together with high-profile cases of artwork forgery, have underpinned the need for sophisticated methodologies for authenticating artwork. In 2018, the J. Paul Getty Museum in Los Angeles finally acknowledged that its ancient Greek sculpture, the Getty Kouros, was in fact a contemporary forgery. The museum acquired the sculpture in 1985 for approximately $9 million; however, subsequent investigations demonstrated the statue's atypical and chronologically incompatible shape, along with fake provenance documents, indicate it was a forgery made recently. [1]. This case exemplifies how vulnerabilities in provenance records can be exploited and highlights the necessity for more robust verification techniques in both traditional and AI-generated art. With growing availability of software to create AI artwork, it has become increasingly challenging to discern between artwork produced through human hands and artwork generated through AI. For instance, in 2022, a digital painting "Théâtre D'opéra Spatial" was created by Jason M. Allen through an AI website called Midjourney and had won a digital artwork competition in Colorado, sparking controversy over whether AI can be used to create valid artwork [10]. Moreover, Allen also encountered problems related to the unauthorized use and merchandising of his work [11]. Collectively, these developments highlight the growing demand for sophisticated AI-powered systems for artwork authentication.

To address these concerns, this research study identifies three key objectives. First, it aims to develop a binary classification model capable of distinguishing between works of art produced by Claude Monet and works produced by other artists, providing a reliable tool for confirming the legitimacy of Monet's style. Second, generalizability of the model is evaluated through its application to works produced by other renowned painters, such as Vincent van Gogh, in an examination of the model's capability to classify a variety of forms with little variation in its output. Third, the effectiveness of the model will be evaluated by its ability to differentiate between works produced by humans and works produced through artificial intelligence, testing for the potential for AI-created replicas of Monet's style to deceive the classifier. Together, these objectives stand to expand our understanding of artificial intelligence in relation to artwork analysis and lay a basis for future development in terms of proper use of AI in artwork authentication, with a view towards resolving growing concerns regarding artwork forgery and integrity in virtual artwork markets.

Methodology

This study utilizes binary classification, and its use is supported by a variety of key factors. Earlier experiments in single-class classification failed, with the models tending to overfit and classify most works of art as Monet, therefore not having acquired meaningful artwork features. In addition, multi-class classification holds a lot of potential but suffers a drop in accuracy with an increased number of artists, with values dropping from 91.23% for 100 artists to 48.97% when moving to 2,368 artists [2]. As such, binary classification yields better accuracy and increased scalability for use in artwork authentication.

ResNet-101 was utilized for its proven effectiveness in resolving vanishing gradient problem through residual connections, allowing for an unobstructed flow of gradients through skip connections between deeper and preceding layers and to the first filters. In other words, the vanishing gradient problem makes it difficult for deep networks to learn effectively, but ResNet overcomes this by using shortcut connections that help preserve important information as it moves through the layers. This architectural feature has proven effective in image classification, allowing for training deeper networks with model accuracy preserved. The use of ResNet deep architecture in combination with careful use of techniques for data augmentation enables the model to learn pertinent features for distinguishing between types of artworks and reduces overfitting challenges.

Experimental Setup/Design

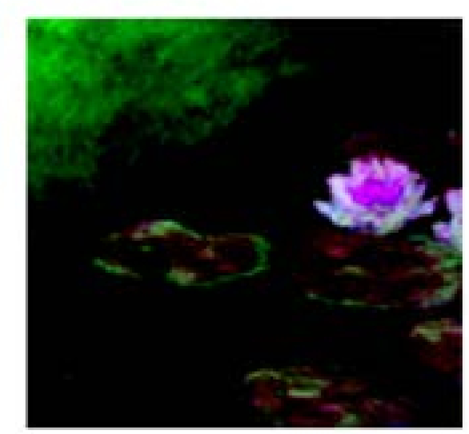
The experiment started with a thorough preprocessing pipeline with the goal of optimizing model performance. As seen in Table 1, there is a list of critical transformations for uniformity: first, a resize of images, then a rotation, with

a 50% chance of a horizontal flipping for generating orientation variance. Shear transformations were also utilized for compensating for perspective mismatches, and color jittering for allowing randomness in terms of

Table 1. Summary of image preprocessing transformations applied during training.

Transformation	Specification
Image Resize:	Crops to 224x224 pixels
Image Rotation:	Rotates between -10 to +10 degrees and a 50% probability to horizontally flip
Image Shear:	Shears from -5 to +5 degrees
Image Color Jitter:	Randomly changes brightness saturation and hue
Image Tensor Conversion:	Change the image to tensor format for model processing
Image Normalize:	Changes mean and standard deviation values for Resnet

Table 2. Two images after processing, finalized and ready for usage. The left image represents a Monet painting, while the right image represents a non-Monet painting.

Monet Image	Non-Monet Image
	

brightness, saturation, and hue. Lastly, tensor conversion and normalization specific to requirements for use with ResNet took place to finalize the image seen in Table 2.

The model's architecture then employed a pre-trained ResNet-101 that was adjusted, specifically for use in binary classification represented in Figure 1. The network begins with an RGB input image of 224x224x3. An RGB image is a digital image where each pixel is composed of three-color channels—red, green, and blue—that combine in varying intensities to produce a wide range of colors. The model then progresses through five layers of convolution (Conv2-Conv5), designed to scan an image for a variety of features including textures, borders, and patterns, with incorporated residual phases allowing for information to pass through unscathed in its journey through the network. Next, average pooling is utilized for flattening, then followed by full connected layers and a dropout layer which randomly deactivates some of the connections to prevent overfitting, culminating in the overall output of binary classification between Monet and non-Monet prediction. This configuration enables efficient feature extraction with proper maintenance of gradient flow through the long network structure.

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The actual training process, as can be observed in the middle of Figure 2, had two iteration blocks per epoch. The first block iterated over initial batches of paintings (Pr-1 through Pr-32), and the second block iterated over batches of larger quantities (Pr-1957 through Pr-1988). Validation after every epoch was done with a dedicated validation set (Pv-1 through Pv-552) to facilitate continuous monitoring of model performance and easy identification of possible overfitting.

The training deployment, in PyTorch, used GPU acceleration with Central Processing Unit fallback support. Performance was tracked using exhaustive metric monitoring, including training and validation loss, accuracy measures, and F1 measures for the Monet class (see Appendix D for a detailed breakdown and the complete training data document). The validation procedure, depicted on the right side of Figure 2, used a similar process to the training phase but without backpropagation. It evaluates its performance based on the unseen data using the same loss, accuracy and F1-score and it prints a confusion matrix for reference.

To avoid overfitting, the early stopping method was invoked with patience of five epochs and automatically saved the model with the best performing validation F1 scores as well as backpropagation in the training phase. This will in turn teach the network to make better predictions over time by constantly refining its weights based

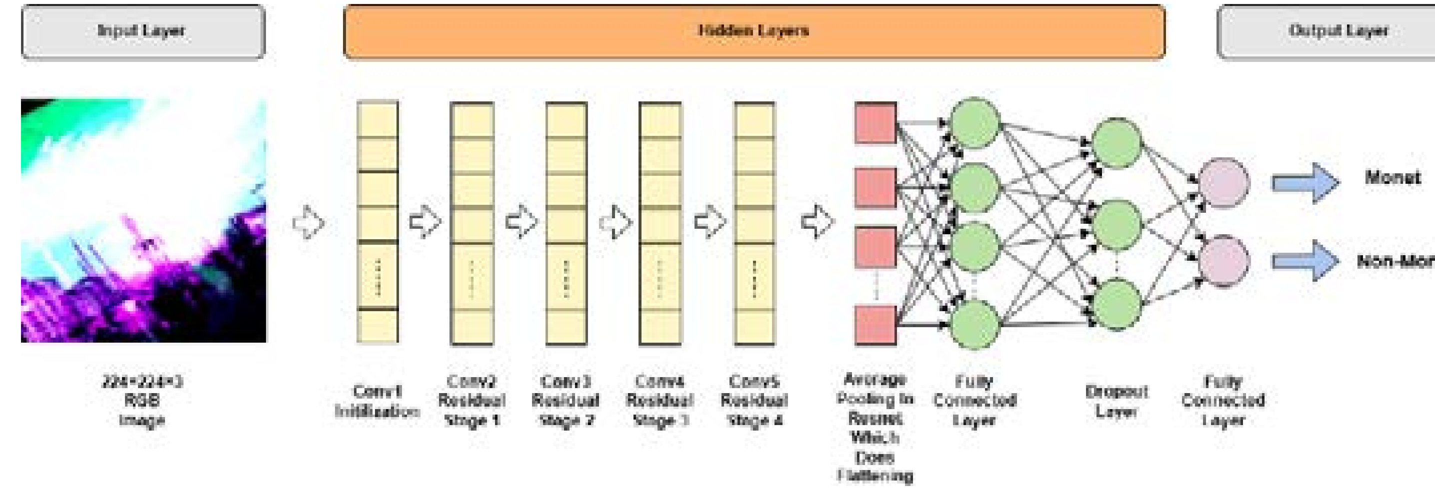


Figure 1. Monet vs non-Monet painting binary classification ResNet-101 architecture. The network takes in a 224×224×3 RGB image and performs several stages of convolutional residuals to it. The final feature maps are subjected to average pooling, followed by fully connected layers and a dropout layer before Monet vs non-Monet classification.

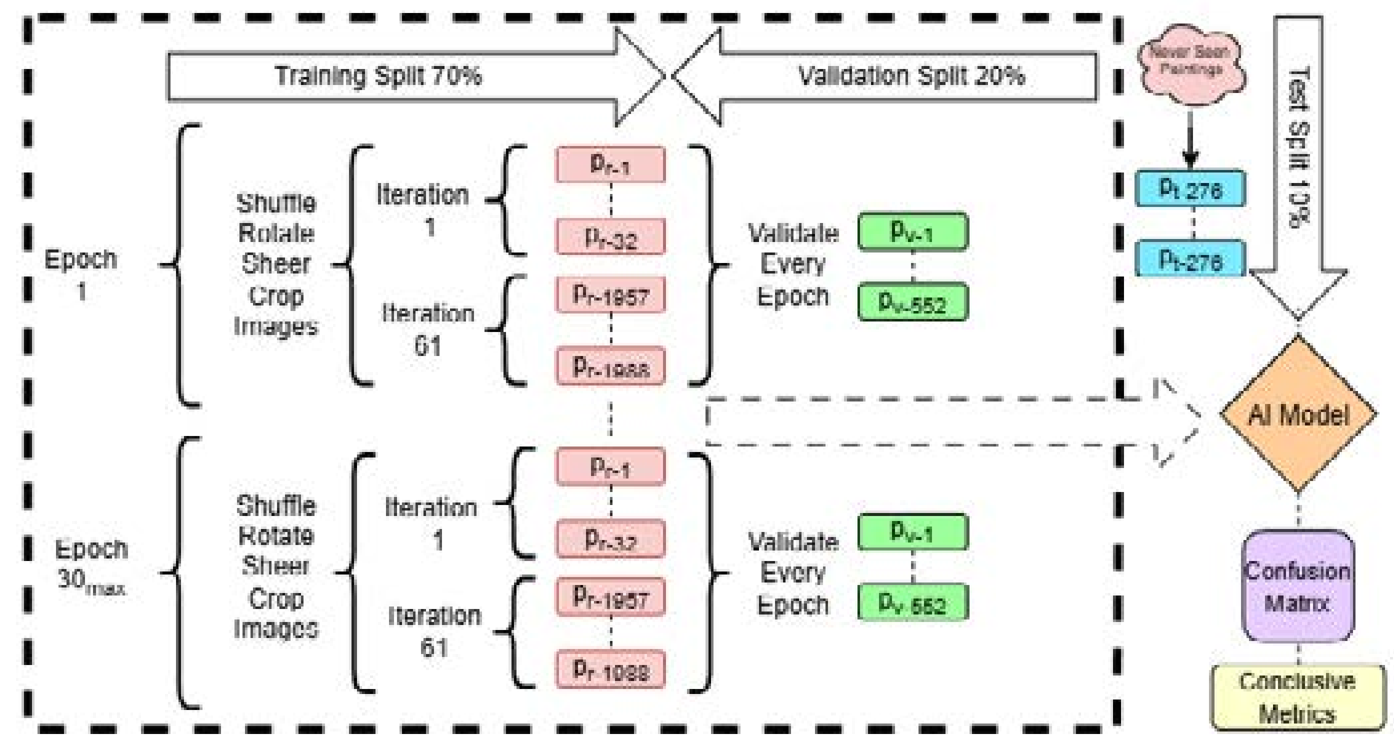


Figure 2. Mapped out distribution of datasets used for training, validation, and testing in the model. The training set is represented by Pr-i, the validation set Pv-i, and the testing set Pt-i. All data sets are mutually exclusive. Each epoch is one complete pass of the entire training dataset through the model.

on how wrong its predictions were and how to correct them accordingly helping the model learn from its mistakes by adjusting and improving for the next round. This entire process of training and testing the model guarantees reproducibility while allowing the flexibility required for tailoring the framework to be used with other artists, as outlined in the research goals.

The testing phase employed the held-out test set (Pt-276) to determine the performance of the finalized model. This testing involved the examination of the confusion matrix and absolute metrics, providing a global accounting of the model's capacity to distinguish Monet and non-Monet works. The pipeline is a robust model for binary classification of art authenticity, with possible uses for both classical forgery detection and artificial generation detection.

Results:

The binary model demonstrated high competence in discriminating between real Monet paintings and non-Monet paintings but with intriguing challenges when confronted with AI-generated images. The results can be examined using various significant features:

1. Model Training and Convergence

The training dynamics in Figure 3 display good model convergence by loss and accuracy metrics over 12 epochs. The training loss exhibited a consistent drop from a level of approximately 0.45 to 0.15, while the validation loss flattened out at a level near 0.20, reflecting effective generalization with minimal overfitting. The accuracy plots indicate an early jump in improvement, which converged to training and validation accuracy levels near approximately 93% by epoch 12. The concurrent trends of the training and validation measures

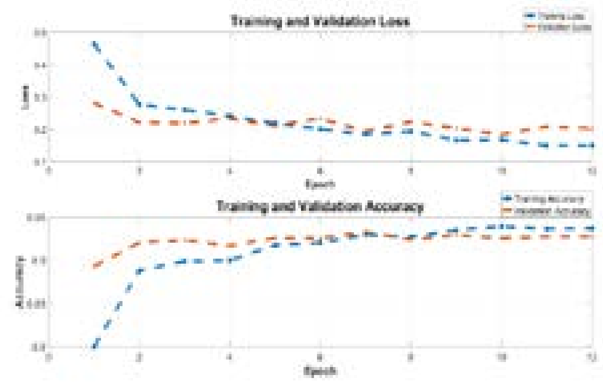
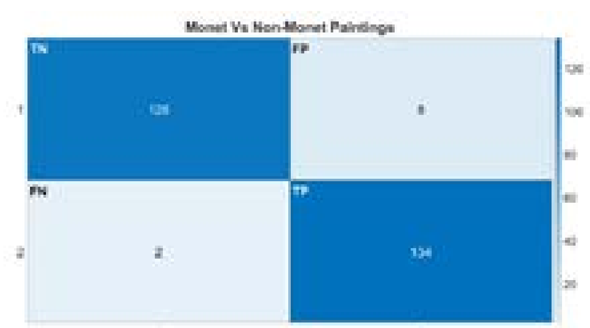


Figure 3. Training Progress of Monet AI Model: Loss and Accuracy Over 12 Epochs. The top graph shows the decrease in both training and validation loss, while the bottom graph illustrates the increase in training and validation accuracy, indicating successful learning and generalization of the model.



Accuracy	Precision	Recall	F1 Score
96.32%	94.37%	98.53%	96.4%

Figure 4. Finalized results from the Monet Model comparing the Monet and Non-Monet datasets, including the confusion matrix and performance metrics.

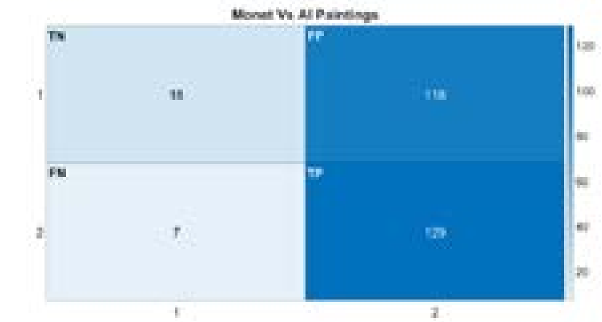
reflect an evenly paced learning process that successfully skirted the usual traps of overfitting or underfitting.

2. Classification Performance on Traditional Artworks

The model was very successful at differentiating between Monet paintings and non-Monet paintings, as presented in the confusion matrix in Figure 4. The performance is 128 true negatives (correct identification of non-Monet paintings) and 134 true positives (correct identification of Monet paintings), along with a minimal number of misclassifications of only 8 false positives and 2 false negatives. This impressive performance is also measured in Figure 4, which lists excellent measures with regards to precision, recall, F1 score, and total accuracy. This performance highlights the model's good performance in classical art verification tasks.

3. AI-Generated Art Detection Challenges

The model performed very poorly when evaluated on AI-generated paintings of Monet, as indicated in Figure 5. The confusion matrix indicates 118 false positives, in which AI-generated paintings were incorrectly classified as actual Monet works, compared to 18 that were classified correctly as non-Monet. Although the model performed well in the classification of actual works of Monet with 129 true positives, this was achieved with compromised overall classification accuracy. Figure 5 illustrates the difficulty of relying on metrics that display declining accuracy (0.5223), even when high recall performance is sustained (0.9485). The precipitate decline in overall accuracy to 0.5404, with a very low non-Monet accuracy of 0.1324, demonstrates the model's issue in differentiating between AI-generated paintings and genuine paintings.



Total Accuracy	Precision	Recall	F1 Score	AI Accuracy
54.04%	52.23%	94.85%	67.36%	

Figure 5. Finalized results from the Monet Model comparing the Monet dataset vs the AI dataset, including the confusion matrix and performance metrics.

Figure 6. Visual comparison of the predictions made by the Monet model. The first row shows the model's predicted probabilities for Monet ("M") and non-Monet ("NM") categories, with perfect accuracy. The second row presents non-Monet images, where the model assigns high probabilities to the non-Monet category, except for one case. The third row shows AI-generated images in Monet's style, where the model's accuracy is close to zero.

4. Visual Analysis

Figure 6 offers required insights through its visual juxtaposition of genuine Monet paintings, non-Monet paintings, and AI-generated paintings. The confidence scores (NM: Non-Monet, M: Monet) are the model's classification choices in various categories. Original Monet paintings all scored high confidence ratings (M: 0.96-1.00), and artificial intelligence-generated paintings also scored high confidence ratings (M: 0.92-1.00). This result indicates that AI-generated paintings have been successful in mimicking Monet's signature stylistic elements to an extent that poses challenge to existing classification techniques. Visual analysis especially brings out the advancement of contemporary AI art generation methods in imitating artist styles.

5. Cross-Artist Validation

The process was also validated on a Van Gogh dataset, with the same set of non-Monet paintings serving as a control group. The Van Gogh model scored 94% accuracy, aligned with the 96.32% performance of the Monet model on conventional artworks. Although the entire confusion matrix of the Van Gogh analysis was not saved due to technical constraints experienced by the study, the comparable accuracy metrics demonstrate the applicability of the binary classification method to the instance of traditional art authentication. Future research would be enhanced by a full replication of the Van Gogh analysis to generate comprehensive performance metrics in line with the ones presented for the Monet classification model.

Conclusion

This research indicates the potential and boundaries of binary classification models in art authentication, in the new frontier of AI-generated artwork. This research yielded many significant findings that add to the field of computational art analysis and authentication.

The binary classification method has reported very high rates of efficiency in traditional art authentication, scoring 96.32% accuracy in Monet and 94% in Van Gogh attributed works. These findings confirm the feasibility of applying binary classification as an efficient means of scalable traditional art verification and indicate that one can create equivalent models for other artists with similar success rates.

This research also brought to light fundamental issues with AI-generated art. The model's evident struggle to distinguish between AI-generated artwork and authentic Monet paintings, with a 0.1324 accuracy rate for AI-generated art, is a fundamental challenge to the art authentication field. This finding highlights the sophisticated nature of modern AI art creation tools and suggests that traditional measures of appraisal might need to be modified in the case of AI-generated work.

The stark difference observed in the performance of the model in validating traditional art versus AI-generated art has strong implications for art authentication. With the increasing complexity level of AI-generated art, there is a vital need for authentication procedures to move beyond binary classification techniques. Future research needs to delve into multimodal authentication techniques that integrate other attributes with visual features, including provenance information, material analysis, and temporal consistency

The findings of this study also carry important implications for comprehending the nature of artistic style and authenticity in an era where artificial intelligence can simulate artistic processes with increasing accuracy. The levels of confidence evident in artwork produced by AI imply that current computational techniques might need to be supplemented with new techniques that can capture the subtle aspects of artistic authenticity.

The current study suggests several productive avenues for future research. These include designing sophisticated neural network architectures specific to AI-generated art detection, combining different classification models within ensemble systems, and investigating unsupervised learning approaches to identifying characteristic artistic signatures that AI programs may struggle to replicate.

And that may not be enough. While the current research points towards directions such as developing sophisticated neural network architectures, ensemble classification models, and unsupervised approaches to detect artistic signatures, simply adding an "AI-generated" category to improve its classification is a feeble solution. All this is temporary relief to this ever-growing issue. With cutting-edge models such as DALL·E 3, Stable Diffusion, and Midjourney repeatedly pushing boundaries of what constitutes art, the line between human and machine creation is rapidly blurring. Instead of relying on a fixed binary framework, future research must embrace a more fluid, context-sensitive model and one that not only involves technical detection but also recasts our very concepts of authenticity as art itself becomes more liquid in the digital world.

Finally, binary classification has tremendous promise in traditional artwork authentication, the challenges presented by AI-generated works necessitate further development of both technological approaches and theoretical underpinnings to art authentication. As the intersection of art and artificial intelligence continues to develop, we need to ensure our methods of artistic intent capture and authentication also move forward.

Data Availability Statement: The data and code for the training, validation, and test classes are available on GitHub via https://github.com/bgorman3/ITSC-3990-AI-Art-Authentication/tree/main

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Appendices

Appendix A: Model Architecture Details

- Input layer: 224x224x3 RGB images
- Convolutional layers: Maintained original ResNet-101 structure
- Dropout rate: 0.3
- Final dense layer: 1 unit with sigmoid activation
- Total trainable parameters: 44.5M

Appendix B: Training Parameters Final Hyperparameters used for Model Training

- Batch size: 32
- Total art: 2761 images
- Initial learning rate: 0.001
- Optimizer: Adam
- Loss function: Binary Cross-Entropy
- Early stopping patience: 5 epochs
- Learning rate reduction factor: 0.1
- Learning rate patience: 3 epochs
- Maximum epochs: 30
- Training/Validation/Test split: 70/20/10

Appendix C: Dataset Composition

	Training	Validation	Test
Monet	957	273	136
Non Monet	977	279	139
AI Generated	0	0	136
Total	1934	552	411

Appendix D: Detailed Training Data Breakdown

- https://bit.ly/4ltOeMc

Appendix E: Technical Terminology

Adam Optimizer: An algorithm for optimization that modifies the learning rate in an adaptive manner for each individual parameter, enhancing its efficiency in training deep neural networks [7].

Average Pooling: Helps to reduce the size of feature maps by computing the average value of regions in an image, helping to retain important features while reducing computational complexity.

Binary Classification: A category of machine learning classifier whereby an algorithm acquires the ability to classify input data into two distinct categories or classes
.

Binary Cross-Entropy Loss: Binary classification loss function that estimates the performance of a model with output as a probability value ranging from 0 to 1 [3].

Confusion Matrix: Matrix utilized to measure the performance of classification models by illustrating the number of correct and incorrect predictions by type.

Deep Learning: A subfield of machine learning which employs neural networks with many layers that are capable of learning representations of data at multiple levels automatically [3].

Epochs: Passing through the entire training dataset once while training a machine learning model.

F1 Score: A model accuracy measure that combines precision and recall into a single score.

Generative Adversarial Networks (GANs): This is a class of machine learning architectures where two adversarial neural networks try to produce new, synthetic instances of data that cannot be distinguished from real data [3].

GPU Acceleration: A process that uses a GPU to speed up computations by handling multiple tasks simultaneously, improving performance in deep learning and other intensive applications.

Normalization: Refers to the process of scaling values acquired on various scales to a single common scale, typically scaling data to a value between 0 and 1 [3].

Overfitting: is a model fault which happens when a machine learning model is overfit to training data, its noise, and variability, hence leading to poor performance on new data [3].

Preprocessing Pipeline: is a collection of data processing routines that are executed to raw data before its use in training a machine learning model [3].

Provenance: The origin, history and chain of custody of an object, document, or piece of art. It helps certify authenticity, ownership, and historical context by tracing where something comes from and how it is transferred overtime and any modifications that have been made or restorations that have been done.

ResNet-101: A deep neural network structure with 101 layers that is capable of training profound networks efficiently with residual connections [4].

Tensor: A multidimensional array which can store data in more than one dimension it is heavily used as the building data structure for deep learning frameworks [3].

Predicting KEGG Orthologs Associated with Microbial Metabolism in Autotrophic Freshwater Microbes Using a Statistical Mmodel

Courtney-Grace Neizer

Courtney-Grace Neizer is projected to graduate in Spring 2025 with a major in Computer Science with a concentration in Bioinformatics. Her research interests are related to leveraging computational tools to study how proteins interact with wider ecosystem dynamics.

Abstract: Microbes play a crucial role in Earth's biogeochemical cycles, yet linking microbial KEGG orthologs to carbon fixation remains challenging due to fragmented datasets and limitations in functional annotation. This study analyzed microbial DNA fragments from Siders Pond in Falmouth, Massachusetts, a salt-stratified meromictic lake. Microbial DNA fragments recovered through metagenomic sequencing of environmental samples were linked to microbial activity to carbon cycling using the DNA-stable isotope probing (DNA-SIP) methods and the important features selected using the LASSO regression statistical model. Environmental samples were incubated with 12C or 13C labeled dissolved inorganic carbon to track microbial carbon incorporation, followed by metagenomic sequencing. Contigs were annotated using both the Protein Families Database (PFAM) and the KEGG Orthology (KO) database, with a bit score threshold of >30, and were linked to excess atom fraction (EAF) values representing microbial carbon assimilation. While both annotation sources were utilized, a greater number of KEGG (Kyoto Encyclopedia of Genes and Genomes) orthologs were identified in this specific dataset, guiding the focus of the analysis. LASSO regression identified key KEGG orthologs potentially involved in carbon cycling. The approach resulted in identifying acyl-CoA synthetase (K00142), BamB – Outer membrane assembly (K17713), glucose-fructose oxidoreductase (K00118), and 23S rRNA pseudouridine2604 synthase (K06182), as key features associated with microbial metabolic processes potentially influencing carbon cycling. Additionally, a domain within hydrazine synthase plays a role in anaerobic ammonium oxidation (PF18582), linking the nitrogen and carbon cycles by converting ammonium and nitric oxide into hydrazine. This suggests a potential role for hydrazine synthesis in microbial carbon metabolism under anoxic conditions. It contributes to a better understanding of microbial roles in carbon cycling and explores new ways of using statistical models to study environmental systems. The findings could help expand knowledge on how microbes influence global carbon cycles. They highlight the potential to uncover novel carbon-fixing pathways, which are crucial for climate and sustainability research.

Research Advisors: Dr. Elaine Luo, Department of Biological Sciences; Dr. Wenyu Gao, Department of Mathematics and Statistics

Keywords: Carbon fixation, chemosynthesis, metagenomics, functional annotation, DNA-SIP, Excess Atom Fraction (EAF), LASSO regression.

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Introduction

Microbes, tiny organisms found everywhere on Earth, play a vital role in maintaining a healthy environment. One of their key contributions is carbon cycling, the process of recycling carbon between the air, soil, and water [1], which supports life on Earth. These organisms can influence Earth's climate by storing carbon in the ground and interacting with carbon in the atmosphere, influencing plant growth and climate balance [2].

However, while microbial roles in carbon cycling are well-established, our ability to predict which microbes are actively fixing carbon remains limited. In the past few decades, new technologies such as DNA sequencing and metagenomics have been widely used to understand the inner universe of these tiny creatures. Traditional genome-based approaches rely on the recovery and assembly of metagenome-assembled genomes (MAGs) and their microbial metabolism inferred using diverse biological databases able to classify and predict their ecological function and biological meaning. Meanwhile, as the diversity and functions of microbial genes and proteins are vast, existing databases often lack the information needed to fully characterize them, leaving many orthologs annotated as unknown or misclassified.

To improve biological classifications, new computational methods are being developed to facilitate the identification and classification of DNA sequences that were not totally recognized in the previous databases. The present study focuses on using an advanced statistical method to link KEGG orthologs associated with microbial metabolism to potential carbon cycling activity. Samples were collected from Siders Pond, a salt-stratified meromictic lake in Massachusetts, where unique microbial communities are capable of fixing carbon in the absence of sunlight. A key challenge in this research is that existing annotation databases, including PFAM and KEGG, sometimes lack the resolution to accurately classify microbial functions, leading to potential mis annotations. To overcome this limitation, this study integrates DNA-SIP with metagenomic sequencing, enabling the identification of microbial KEGG orthologs potentially involved in carbon fixation activity. This represents the first recorded instance of metagenomic-SIP being applied in a freshwater system, demonstrating its potential to validate functional predictions beyond database annotations.

Water samples were collected, filtered to isolate bacterial cells, and incubated using ^{13}C (label) or 12C (control) to track carbon incorporation over time. The excess atom fraction (EAF) analysis was applied to measure the incorporation of isotopically labeled carbon (^{13}C) into microbial genomes, allowing the identification of key microbial players in carbon fixation. By using this method, we were able to identify organisms performing chemosynthesis—carbon fixation without sunlight— through the incorporation of ^{13}C revealing their ability to perform carbon fixation in a light-limited environment. By calculating EAF values for each DNA sequence (contig) obtained from metagenomic sequencing, the objective was to associate these values with specific contigs to infer the potential metabolic functions represented by KEGG orthologs, which may be linked to microbial carbon cycling.

To analyze this data, this study employs LASSO (Least Absolute Shrinkage and Selection Operator) regression, a statistical technique that identifies the most relevant KEGG orthologs from high-dimensional metagenomic data. LASSO was chosen because it effectively reduces large, complex datasets by selecting the most relevant features while minimizing noise. Previous studies have applied machine learning to metagenomic data [4], but few have directly linked EAF-based functional analysis to predictive models of carbon cycling.

By integrating metagenomics, EAF calculations, and statistical methods, this research aims to improve our understanding of microbial roles in carbon fixation and identifying of novel carbon-fixing pathways. Existing databases have limited ability to detect new pathways. To address this issue, this study seeks to fill that gap by uncovering

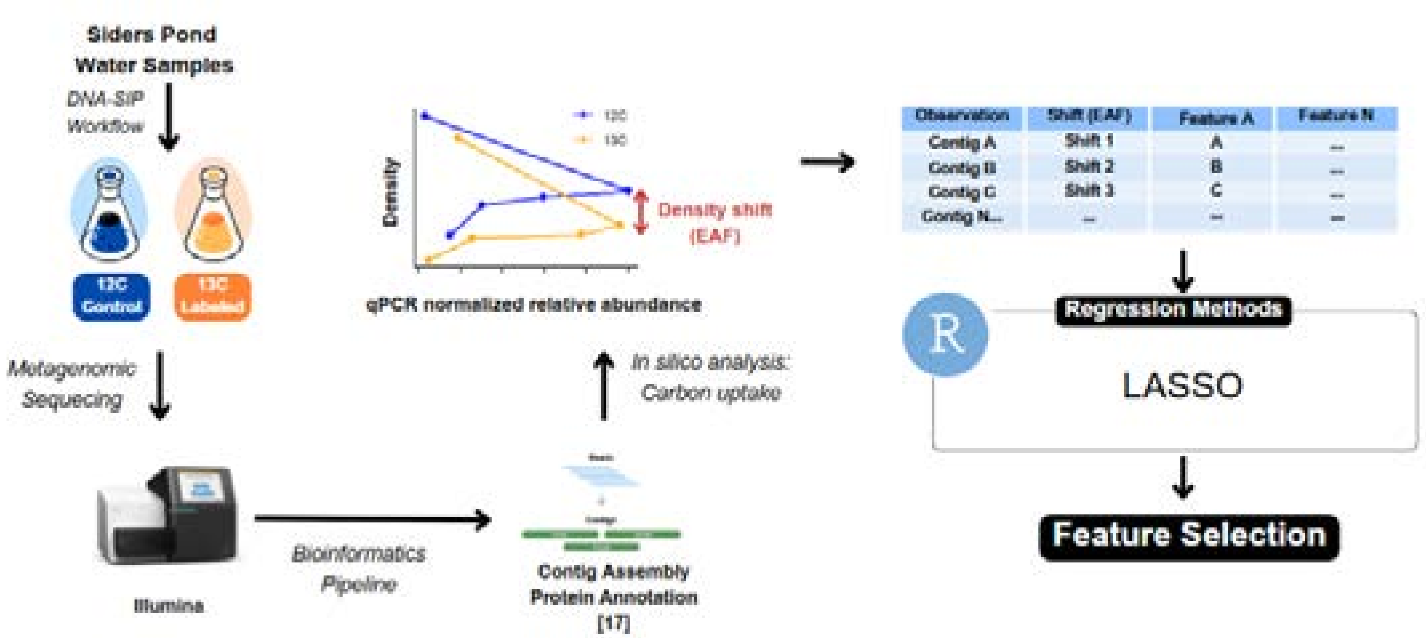

Figure 1. Water samples were collected from Siders Pond, a meromictic lake in Massachusetts. DNA-SIP was used to track microbial carbon fixation activity by incorporating either ^{13}C-labeled or ^{12}C-control dissolved inorganic carbon (DIC). DNA was sequenced, assembled into contigs, and analyzed for density shifts (EAF) to identify carbon fixation. The dataset containing EAF values and features was analyzed using LASSO regression in R programming language for statistical computing.

previously unannotated KEGG orthologs linked to carbon cycling.

Materials and Methods:

Sample Collection and DNA Processing

Environmental water samples were collected from Siders Pond, a meromictic lake in Massachusetts, where microbial communities engage in light-independent carbon fixation. Water samples were filtered to isolate bacterial cells, followed by a 7-day incubation to track carbon incorporation over time. After incubation, microbial DNA was extracted and sequenced, generating raw reads that were assembled into contigs, which are DNA fragments containing genomic information about microbial activity. The DNA assembly process moves from readings to contigs, scaffolds, and full genomes [17].

To ensure data quality, sequencing data underwent preprocessing, including the removal of low-quality sequences to minimize errors. Contigs were annotated using the Protein Families (PFAM) database to identify protein domains, and sparsity in the dataset was addressed by replacing missing annotations with zeros [5]. KEGG Ortholog (KO) annotations were also included in the dataset and used to interpret microbial metabolic functions. Although the study initially aimed to focus on protein-level annotations, the final analysis emphasized KEGG orthologs due to their higher representation in this dataset, allowing for functional interpretation across gene, protein, and pathway levels.

Dataset Selection and Feature Processing:

This study exclusively utilized the 5-kilobase (kb) contig dataset, as it was the primary dataset analyzed within the scope and timeline of the project. With its focus being on microbial sequences with annotated KEGG orthologs and functional domains associated with carbon cycling. To refine the dataset, features were filtered using a bit score threshold of ≥30, ensuring high-confidence annotations. Features with scores below this threshold were excluded to ensure high-confidence annotation [6,7]. Additionally, Excess Atom Fraction (EAF) analysis was incorporated to identify chemosynthetic microbial activity by tracking the incorporation of ^{13}C-labeled carbon into microbial genomes.

Dataset	RMSE
Training	0.0262900
Testing	0.0277889

Table 1. Root Mean Squared Error (RMSE) for LASSO Model. Representation of the RMSE values for the training and testing datasets, indicating the model's predictive performance. Lower RMSE values suggest that the top 10 selected features, which included nine KEGG orthologs and one PFAM annotated protein domain, contribute meaningfully to carbon cycling predictions. However, further validation is necessary to confirm their ecological relevance. Visualization generated using R.

Statistical Approach

To predict microbial contributions to carbon cycling, LASSO regression was applied. LASSO was selected for its ability to perform feature selection in high-dimensional datasets by identifying the most relevant KEGG orthologs while minimizing overfitting. The dataset was split into 80% training and 20% testing subsets, and cross-validation was performed to optimize model performance. The Root Mean Squared Error (RMSE) was calculated to assess the accuracy of predictions.

Data Analysis and Flow:

The analytical workflow consisted of several steps. First, raw sequencing data were filtered, and missing values were addressed through preprocessing. Next, a bit score threshold was applied to the annotated dataset, followed by LASSO regression to identify significant microbial features associated with carbon cycling. The dataset was then divided into training and testing sets, and model performance was evaluated based on RMSE. The selected features included KEGG orthologs and one PFAM protein domain, which were further examined to explore their potential roles in microbial carbon fixation.

Computational Tools

All analyses were conducted using R, utilizing the glmnet package for LASSO regression and tidyverse for data preprocessing [14].

Data Availability

The dataset analyzed in this study consists of metagenomic sequencing data processed to extract contig-based features.

Results

This study identifies a subset of PFAM features that are potentially associated with microbial functions related to carbon cycling using EAF as a resource to measure the absorption of 13C by chemosynthetic microbes. The LASSO regression model selected these features based on the EAF measurement. The findings reinforce the potential of contig-based datasets for functional profiling by identifying microbial metabolic orthologs that may play critical roles in carbon cycling.

The bar plot (Figure 2) presents the top 10 microbial features selected by LASSO regression, ranked based on their association with excess atom fraction (EAF) values. The x-axis represents the coefficient values, indicating the relative contribution of each feature to the model's predictions. The selected features include nine KEGG orthologs and one PFAM-annotated protein domain. Features with larger absolute coefficients have a stronger predictive relationship with microbial carbon cycling activity. In LASSO regression, features with larger absolute coefficients are more predictive within the model, as the method applies a penalty to less relevant variables, shrinking them to zero while retaining the most informative ones [18]. In this study, positive coefficients suggest a potential association with increased microbial carbon fixation, while negative coefficients may indicate an inverse relationship. However, as LASSO selects features based on statistical importance rather than direct biological causation, further validation is necessary to confirm functional relevance [18].

The y-axis lists the top 10 microbial features identified by LASSO regression, including nine KEGG orthologs and one PFAM domain (PF18582, hydrazine synthase subunit). These features were selected based on their association with excess atom fraction (EAF) values, indicating potential involvement in microbial carbon assimilation. While several of the identified orthologs have known roles in metabolism, membrane transport, and signaling, their specific contributions to carbon fixation remain to be experimentally validated [10]. Their selection by the model indicates that they were among the most predictive features in this dataset, but additional biological validation is required to determine whether they directly contribute to carbon cycling processes.

Discussion

The results of this study

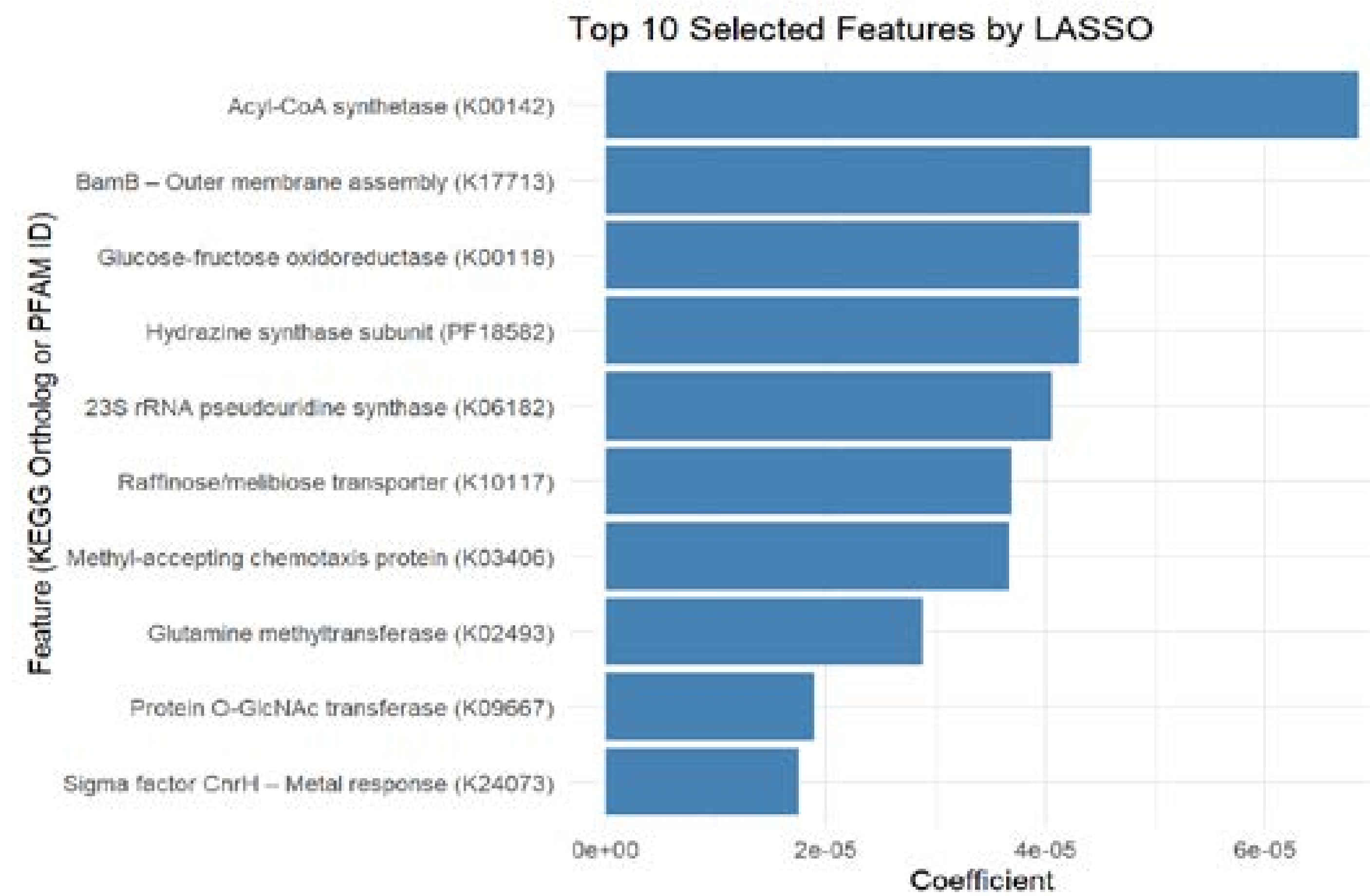

Figure 2. Top 10 Selected Features by LASSO. This figure illustrates the top microbial features identified using LASSO regression, ranked by coefficient magnitude. The features include nine KEGG orthologs and one PFAM domain, selected for their association with excess atom fraction (EAF) values. Features with larger absolute coefficients were more influential in the model, though their direct roles in microbial carbon cycling remain to be validated. Visualization generated using R.

demonstrate the potential use of LASSO regression in identifying microbial features associated with carbon fixation. The RMSE values for the training and testing datasets (Table 1) suggest that the model performed well, indicating that the selected KEGG orthologs and PFAM domain may play important roles in microbial carbon cycling. Specifically, the model had a training RMSE of 0.0263 and a testing RMSE of 0.0278, indicating that it effectively identified key features while maintaining reliable prediction accuracy.

Figure 2 visualizes the top 10 microbial features identified by the LASSO model, ranked by their importance in predicting microbial contributions to carbon cycling. The ranking of these features provides insight into microbial metabolism, particularly carbon fixation, the process by which microbes capture inorganic carbon and convert it into organic matter. The LASSO model identified ten microbial features, but five were selected for discussion based on their prominence in the bar plot and potential biological relevance. The approach resulted in identifying five key microbial features from the LASSO model that may influence carbon cycling. These included acyl-CoA synthetase (K00142), BamB – outer membrane assembly (K17713), glucose-fructose oxidoreductase (K00118), 23S rRNA pseudouridine2604 synthase (K06182), and a hydrazine synthase alpha subunit domain (PF18582). Acyl-CoA synthetase plays a central role in fatty acid metabolism by catalyzing the activation of fatty acids, a crucial step for their breakdown and energy production [19]. BamB is involved in the assembly of outer membrane proteins, supporting structural integrity and interaction with the environment [20]. Glucose-fructose oxidoreductase facilitates the oxidation of sugars and may contribute to microbial energy generation, particularly in fluctuating redox environments [21]. 23S rRNA pseudouridine2604 synthase introduces modifications to ribosomal RNA, which can enhance ribosomal stability and efficiency under environmental stress, potentially influencing protein synthesis in carbon-fixing microbes [22]. The hydrazine synthase domain (PF18582), found in anammox bacteria, participates in anaerobic ammonium oxidation. It catalyzes a two-step reaction: nitric oxide is first reduced to hydroxylamine, which is then condensed with ammonium to form hydrazine. This process links nitrogen and carbon cycling in oxygen-limited environments by supporting microbial energy conservation through chemosynthesis [23]. These microbial features may play important roles in metabolism, but their specific contributions to carbon cycling require further investigation. Future research incorporating KEGG Orthology (KO)-based pathway analysis could help clarify how these orthologs and domains function within broader microbial metabolic networks.

While these findings provide valuable insights, some limitations must be considered. First, this study analyzed contigs, which are short fragments of microbial DNA rather than complete genomes. This means that some connections between proteins and metabolic pathways may be incomplete. While PFAM annotations provide useful classifications of microbial proteins, they may not fully capture the diversity of microbial function. This highlights the need for more comprehensive genome sequencing and expanded annotation databases to improve future research.

To further build on these findings, future studies should explore alternative statistical learning models such as Elastic Net, Principal Component Regression (PCR), and Ridge Regression. Additionally, incorporating machine learning approaches like XGBoost, Random Forest, and neural networks could enhance predictive accuracy and

refine feature selection by capturing complex relationships within the data. Furthermore, expanding the data set to include samples from various environmental conditions would help validate the generalizability of these results.

Conclusion

This study demonstrated that statistical methods could help predict microbial contributions to carbon cycling, even when working with incomplete genetic data. By combining protein family annotations from PFAM with LASSO regression, this research identified microbial proteins that may play an important role in carbon fixation and nutrient cycling.

Among the most significant features selected by the model were acyl-CoA synthetase (K00142), BamB – outer membrane assembly (K17713), glucose-fructose oxidoreductase (K00118), 23S rRNA pseudouridine2604 synthase (K06182), and the hydrazine synthase alpha subunit middle domain (PF18582). These microbial features are linked to a variety of metabolic processes, including fatty acid activation, membrane protein assembly, sugar oxidation, RNA modification, and anaerobic ammonium oxidation. Their selection suggests that microbial contributions to carbon cycling likely involve diverse biochemical pathways. However, the exact roles of these KEGG orthologs and the PFAM-annotated protein domain in carbon fixation remain uncertain, and further research is needed to confirm their biological significance. However, the specific contributions of these KEGG orthologs and protein domains to carbon fixation remain to be validated through experimental studies.

Although both KEGG Orthology (KO) terms and PFAM annotations were included in the dataset, most features selected by LASSO regression in this specific analysis were associated with KEGG orthologs. As a result, the analysis primarily focused on KO-based annotations to explore microbial metabolic contributions, while PFAM domain information was incorporated where available.

Beyond the scope of this study, understanding microbial roles in carbon cycling has important environmental implications. Microbial communities influence carbon sequestration, the process of capturing and storing carbon to reduce atmospheric CO_2. Refining statistical models to improve predictions of microbial contributions to carbon cycling could provide valuable insights for environmental management and climate change mitigation.

Further research should expand the dataset to include additional environmental samples, improve genome assembly techniques, and explore additional statistical and computational approaches to refine predictive accuracy. Incorporating more functional annotation tools, including KO pathway analysis, may also provide a deeper understanding of microbial metabolism beyond carbon cycling.

This study highlights the potential of integrating metagenomics, statistical modeling, and ortholog-based annotation databases to study complex biological systems, particularly microbial contributions to carbon cycling. As computational methods continue to advance, approaches like metagenomic-SIP combined with feature selection models such as LASSO will be essential for identifying novel microbial pathways involved in processes like carbon fixation, nitrogen cycling, and other ecosystem-level biogeochemical functions that influence climate and environmental health.

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Breaching the Walls: Strategy in the Babylonian Seige of Jerusalem

Jacob A. Majure

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Abstract: The city of Jerusalem fell to a Babylonian siege in 586 B.C. Historians recognize the validity of the siege but put little effort into an analysis of the siege tactics utilized by the Babylonians. Most historical knowledge of the sieges comes from biblical accounts within the books of Ezekiel, Jeremiah, and 2 Kings. However, in 2019, University of North Carolina at Charlotte students uncovered artifacts confirming accounts of the siege at UNCC's dig site in Jerusalem. Among the artifacts, UNCC students discovered a Scythian arrowhead and a golden earring in an ashen layer. The implications of this finding further validate the biblical accounts. This discovery allows historians to revisit the siege with a clearer view of the events of theconquest. This paper analyzes biblical accounts, prior historical research, and newfound artifacts, alongside a historical understanding of the siege methodology of the time, to establish a picture of the two years Jerusalem spent under siege. This paper uses these sources to paint a portrait of the methodology employed by King Nebuchadnezzar of Babylon during the siege. Such as, what wall the Babylonians breached the city from, what tools they used to breach the wall, and why the Babylonians "hesitated" following the breach. This paper proposes a theory of exact methods used by the Babylonians to conduct the siege that led to the destruction of one of the mosthistorically significant cities in the world.

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Key Words: Jerusalem, Babylonian Siege, Nebuchadnezzar II, 586 BC, siege warfare, military strategy, ancient warfare

Introduction

Jerusalem stands today after surviving assaults from the Persians, Romans, Assyrians, Greeks, and Babylonians. Jerusalem stood firm against Sennacherib and the Assyrians in 701. However, in 587/586 BC, the Neo-Babylonian empire besieged and destroyed the city.[1] The Babylonians, led by King Nebuchadnezzar II, destroyed and burned down all of Jerusalem. The siege left the central city of the kingdom of Judah in ruins. Until recently, biblical accounts alone provided historical context to the siege. The siege is mentioned throughout the Old Testament in the books of Jeremiah, Ezekiel, and 2 Kings.[2]

However, in 2019, UNC Charlotte

students excavated artifacts that potentially confirm the utter devastation Jerusalem faced 2,500 years ago. The university students discovered a Scythian arrowhead and a gold earring in an ashen layer. While the biblical sources provide substantial evidence, they include potential biases that might impact an objective understanding of the siege. For example, the biblical accounts have a clear negative view of the reigning king of Judah, Zedekiah; because of this, they attribute the siege to Zedekiah's unholiness. With their negative view of Zedekiah, it is difficult to understand the deeper reasoning behind Nebucadnezzar's actions. The discovery of new evidence at UNCC's dig site provides clarity and confirmation to the potentially biased sources. This paper will show how these findings further enforce existing historical impressions from biblical accounts. These findings and their confirmation of biblical sources make revisiting the history of the siege a necessity.[3]

Few historians have viewed the siege from a military history perspective. This perspective allows for a deeper analysis of the strategic decisions made by Nebuchadnezzar II, contrasting his successful siege with his unsuccessful attempt a decade prior. Through the use of primary and secondary source evidence, this paper seeks to paint a picture of the siege methodology and timeline of the siege.

This paper will analyze biblical accounts, prior historical research, and newfound artifacts, alongside historical understanding of siege methodology at the time to establish a vivid picture of the two years the Babyloniand spent besieging Jerusalem. By examining the fortifications of Jerusalem and the armaments of the Babylonians, this paper will propose a theory of the methods used by the Babylonians to conduct the siege.

Historical Context:

Dating the Siege

Many accounts date this siege as 587 BC, while others date it to 586 BC. This conflict arises from confusion and lack of information from accounts. Typically, dates within the Old Testament biblical text are given as years since the ruler came to power. For example, the book of Jeremiah dates the second Babylonian siege of Jerusalem "in the ninth year of Zedekiah king of Judah, in the tenth month."[4] The conflict arises when trying to place the time of Zedekiah's rise to the throne. In the text, the new year marks Zedekiah's rise to power. However, the text does not clarify whether this refers to the Tishrei or the Nisan new year.[5] For clarity, going forward, this essay assumes the use of the Nisan calendar. That places the completion of the siege in August of 587 BC.

Dominance of the Babylonian Empire

The Babylonian empire under Nebuchadnezzar II imposed its power upon the kingdom of Judah and the surrounding area. The Babylonian Empire filled the gap left by the fall of the Assyrian Empire in the seventh century. Historian D.J. Wiseman described Nebuchadnezzar after gaining power as "march[ing] about unopposed."[6] Nebuchadnezzar goes on to be described as the just king. As he established his dominance in the Near East, he found resistance in Jerusalem.[7]

Jehoiakim ruled as the King of Judah during the late seventh and early sixth century BC. He operated Jerusalem as a vassal state of Egypt until 605 BC when Nebuchadnezzar II forced Jehoiakim into Babylonian allegiance. Nebuchadnezzar intended for Jehoiakim to "reinforce the southern border."[8]

In the early sixth century, Jehoiakim expressed his disdain for his new ruler, Nebuchadnezzar II. Jerusalem was subsequently besieged by Babylon in 597 BC. Nebuchadnezzar placed Zedekiah in power as the new ruler. This laid the foundation for Zedekiah's rebellion against Nebuchadnezzar II just a decade later and the siege of 587/586 BC, which this essay focuses on.[9]

Methods of Siege Warfare

To conduct a siege, military tacticians cut off supply lines into a city, apply pressure to city walls, and attempt to breach city walls. When besieging a city, the besiegers seek to starve the besieged city of resources and force a surrender. Siege warfare requires patience. Few sieges conclude in less than a year; when they do, it arises from surrender or diplomacy. The final goal of a siege is to force a surrender or to breach the city walls.[10]

The first important step in a siege is a blockade. The army besieging the city creates a blockade to prevent resources from entering the city. These resources might include food, water, and people. By preventing anyone from entering or exiting the city, they ensure that the interior population loses the strength to continue resistance. Historians note these methods in the siege of Megiddo, and even centuries later, in the sieges done by Sennacherib and Nebuchadnezzar II. Besieging a city was a lengthy process. The barricade involved much more than positioning soldiers around the city walls. It involved the construction of structures and fortifications. The main focus of the blockade was placed on the gates and critical points of escape around the city. As described in this Egyptian royal inscription. "They measured the town, surrounded [it] with a ditch, and walled [it] up with fresh timber from all their fruit trees." The entire method focuses on entrapping the city, as described best by Sennacherib,

> *Himself [Hezekiah] I made a prisoner in Jerusalem, his royal residence like a bird cage. I blocked him with fortified posts and made departure via the gate of his city into an unbearable ordeal.*[12]

Despite the goal being stalemate, sieges include active assaults on the walls and gates of the besieged city. Active assaults force the city to use vital and scarce resources to retaliate. The besieging force seeks to force negotiations and to create the means for a surrender.[13]

Diplomacy also played a significant role in siege warfare. Sieges potentially lasted years on end, so leaders sought to negotiate to end the long process before the city and population were further damaged. Throughout history, negotiations arising from sieges led to compromise, treaties, and surrender.[14]

If negotiations fail, the invading force might decide to attempt to breach the city walls. Popular media often includes battering rams in depictions of siege warfare. These large devices struck city gates until they crumbled and allowed entry. In many instances, geographic features prevented sieging forces from reaching city walls for the use of battering rams. In these circumstances, many armies constructed siege ramps. These large mounds of dirt allowed troops to reach walls that had geographic advantages so that battering rams could be used to bring down the walls.[15]

Despite their popularity, armies did not rely entirely on battering rams for breaching city walls. Certain cities, with walls as thick as four meters, rendered battering rams ineffective. Instead, sieging forces relied on sapping devices, another tool for breaching walls, which saw frequent use during the sixth century BC. An inscription depicting the siege of Lachish shows the use of sappers by the Assyrians to undermine the wall. When sapping a wall, engineers dug a deep crater beneath a portion of the city walls, then they chipped away at the wall's foundation. Eventually, this collapsed the wall, allowing entry into the city.[17]

Historically Adjacent Sieges

Jacob H. Katzenstein's research on the siege of Tyre relates closely to the Babylonian siege of 587 BC. This siege was conducted during the same time period of the early sixth century BC. At this time, the Babylonians besieged the city of Tyre. The context of this siege and the mechanics of it contribute to a historic understanding of the formalities within Babylonian siege warfare.[18]

Similarly, the sieges of the Assyrians in the early eighth century BC show further methods of siege warfare. The siege of Lachish conducted by the Assyrians in 701 contributes to the wider understanding of siege warfare methods of that time. Similarly, it is relatively close to Jerusalem, to the southwest, so the Assyrians conducted the siege with methods common to the region. The Lachish siege required the use of a siege ramp,[19] which was constructed to breach the city. The siege ramp at Lachish left evidence still visible today. Due to the lack of similar evidence in Jerusalem, researchers find it unlikely that a siege ramp was used there. This rules out the southern and eastern walls for breach of Jerusalem. If the Babylonians breached these walls, evidence of a ramp to traverse the Kidron and Sillom valleys would be present.[20]

In 604 BC, Nebuchadnezzar used his immense military strength to destroy the city of Ashkelon. As a coastal city, it would have been a challenge similar to Tyre. That is because it had easier access to imports of resources. It also had support from Egyptian forces. Nebuchadnezzar, in his first year, was able to destroy the city of Ashkelon, cementing his place as a powerful military ruler. Research from Alexander Fatalkin at Tel-Aviv University shows that Ashkelon was very well fortified and militarily powerful. Nebuchadnezzar attacked in the winter months to prevent the possibility of Egyptian reinforcements being sent by water.[21] This strategy reflects the military mind of Nebuchadnezzar. Similarly, the confidence of attacking within the winter months implies a strong military force.

Geographic and Natural Features of Jerusalem

Jerusalem benefits from its many natural features that contribute to the fortifications. The Kidron and Hinnom valleys act as two of the most important natural siege deterrents. The Kidron Valley runs parallel to the east side of the Temple Mount and down past the city of David. Similarly, the Hinnom valley runs adjacent to the south walls of the city. The locations of the city in relation to the valleys forced any attacker to focus assault on the western or northern wall. Nearby springs also allowed for ease of access to water. The Gihon spring was just outside the eastern wall. In preparation for the Assyrian siege of 701, Hezekiah had the spring blocked up so that it was inaccessible from the outside. Hezekiah's tunnel allowed the water to be accessed inside the walls at the pool of Siloam.[22]

Previous Research & Historiography:

Until recently, the Bible alone provided a source to the experience of this siege. Much of the existing research focuses on the city's fall instead of the siege because the biblical texts highlight these events. With less accessible evidence, much of the interest stemmed from three books: 2 Kings, Ezekiel, and Jeremiah. Because of the lack of physical evidence, most of the previous research highlights historically-adjacent sieges of

the period. Recently, excavations at the UNCC Mount Zion Project uncovered artifacts that confirm the biblical account. To understand the siege itself, one should focus on adjacent sieges for context. Some of those include the siege of Lachish in 701, the siege of Tyre, and the earlier Babylonian siege of Jerusalem.

Biblical Accounts

The biblical accounts that focus on the fall of Jerusalem in 587 BC come from three books. The prophet Ezekiel wrote the first of these books. Jeremiah wrote the other two books, Jeremiah and 2 Kings.

Ezekiel wrote the book of Ezekiel during his imprisonment in Babylon following the siege. The book focuses on the punishment that comes from unrepented sin. Ezekiel disdains King Zedekiah for his impious actions. Ezekiel saw Zedekiah's imprisonment by Nebuchadnezzar II as a warranted punishment because he broke the bond he had made with Nebuchadnezzar II. The book of Ezekiel displays one perspective of Zedekiah's rule. Zedekiah agreed to an oath with Nebuchadnezzar II that Jerusalem would operate as a vassal state of the Babylonian Empire. However, Zedekiah sought to gain independence and strength for Jerusalem separate from Babylonian rule. In Ezekiel 17:16 and 18, he prophesied, "he [Zedekiah] shall die in Babylon, in the land of the king who put him on the throne [Nebuchadnezzar II], whose oath he despised and whose treaty he broke... He despised the oath by breaking the covenant. Because he had given his hand in pledge and yet did all these things, he shall not escape."[23] Ezekiel states in this excerpt that when Zedekiah broke his oath, he doomed himself to death in prison.[24]

The book of Jeremiah is similarly written from Babylon and is an account of the destruction of Jerusalem as a warning against sin. Jeremiah saw the disobedience of Zedekiah as the great catalyst for the destruction. He attributed disobedience to God, in reference to keeping slaves, as the reason that Jerusalem's fall was as violent as it was. Jeremiah 34:17, "Therefore this is what the Lord says: You have not obeyed me; you have not proclaimed freedom to your own people. So I now proclaim 'freedom' for you, declares the Lord—'freedom' to fall by the sword, plague, and famine. I will make you abhorrent to all the kingdoms of the earth."[25] Like Ezekiel, this text attributes Jerusalem's fall solely to the impiety of Zedekiah.[26]

The book of 2 Kings discusses the same siege. Jeremiah continues to communicate that Zedekiah's disobedience led to the siege and eventual destruction of Jerusalem. 2 Kings differs from the other two works by focusing on the experience of citizens within Jerusalem. Jeremiah used this work to chronicle the violence and starvation experienced by the citizens during the siege. This further built his disdain for Zedekiah.[27]

Each of these works chronicles the violence of the siege while also highlighting the political ramifications of Zedekiah's actions. Some important features of the siege stand through all of these accounts. Each of these books mentions famine within the siege.[28] While details are scarce, this shows Nebuchadnezzar II's effectiveness at cutting off resource lines into the city. The biblical accounts also each mention the subsequent burning of the city, and the destruction of the walls following the siege. Despite the majority of these works focusing on the impiety of Zedekiah, the consistent presence of famine and city destruction hold historic significance. Specifically, the mention of the falling of siege walls in Jeremiah.[29] This essay discusses the implications of this verse as an indicator of the siege methodology used by the Babylonian empire. Understanding the siege through the

Nebuchadnezzar Chronicle

In 1956, Archaeologist Donald J. Wiseman published his translation of the Nebuchadnezzar Chronicle, an ancient Babylonian text that tells the accounts of Nebuchadnezzar's first assault on Jerusalem. This tablet describes the events of the first eleven years of Nebuchadnezzar II's rule as king of the Babylonian empire. Throughout his career, he continuously referenced this text as a cornerstone of the history of the Near East. As a professor at the University of London, Wiseman specialized in Assyrian history and notably contributed to the research of Babylonian history. Being a biblical scholar, he wrote about the Near East in its context with biblical recordings. His scholarship is well respected in the field. Wiseman discussed the siege in his work Nebuchadrezzar and Babylon. This was an updated work that revised his original publication. In this work, he used additional texts and historical context from notable scholars such as Katzenstein, Weidner, Malamat, and others while also studying biblical accounts of Jeremiah and 2 Kings. He interpreted this data and historiography to deepen understanding of the political ramifications of the siege.[30]

He discussed the political hostility that Zedekiah, the reigning king of Jerusalem, had towards Nebuchadnezzar and Babylon and all that led to Zedekiah gaining power after the 596 BC siege. *Nebuchadrezzar and Babylon* shows the ways that Nebuchadnezzar II headed the kingdom of Babylon's growth through the use of swift military action, taking brief moments of peace to indulge in the support of his allies.[31] Wiseman suggested that political rivalries with Egypt motivated much of the actions by Nebuchadnezzar II.[32] The threat of military action from Egypt drove Nebuchadnezzar II to paranoia and the urge to secure his southern borders with Jerusalem.

Wiseman established a view of the political landscape of the time and how individual figures reacted to the attack. His views differed somewhat from those of other scholars, specifically his differing views on the dating of the siege. His text helps to provide a good basis of understanding for the political implications and some of the military action of the siege. This essay differs from Wiseman's interpretation by contributing a new theory to explain the pause after the city walls broke before the Babylonians burned the city. Following the breach of the city walls, the Babylonians hesitated about a month before pillaging Jerusalem. Wiseman suggested that Zedekiah and Nebuchadnezzar II spent this time in deliberation. This will be further discussed in the Discussion section below.[33]

UNC Charlotte Mount Zion Project

In a recent excavation by the University of North Carolina at Charlotte (UNCC), students discovered artifacts that confirm biblical accounts of the Babylonian siege. UNCC established the Mount Zion project in 2014 to teach students the methods of archaeological research through first-hand excavation experience. At this dig site, students learn with their professors about the intricacies of archaeological practice and study through hands-on work with experts. Students and volunteers spend the summer in the old city studying the culture while actively participating in the discovery of history. As described by representatives, "The purpose of the Mount Zion Project is to expose, examine and preserve all levels of habitation over the course of Jerusalem's 3,000-year history."[34] Students have continued this mission year after year, with interruptions coming in 2020 due to COVID-19.[35]

In 2019, the excavation uncovered two very important artifacts: a gold earring, and an arrowhead. The students discovered these artifacts in an ashen layer. The discovery of an ashen layer within city walls does not imply anything unique. Around the time of the siege, citizens often burned trash or grilled meat within the city walls. However, the inclusion of these artifacts, coupled with the ashen layer, holds vast significance for the history of the city. The context of the arrowhead implies that this fire was not for residential purposes. As said by expert and director Shimon Gibson, "It could be ashy deposits removed from ovens, or it could be localized burning of garbage. However, in this case, the combination of an ashy layer full of artifacts, mixed with arrowheads and a very special ornament, indicates some kind of devastation and destruction. Nobody abandons golden jewelry, and nobody has arrowheads in their domestic refuse."[36] Professor Gibson explained that no single artifact alone confirms any findings, but the combination of the arrowhead, jewelry, and ashen layer tells a deeper story. The arrowhead found was a Scythian arrowhead. The Babylonians used Scythian arrowheads at the time of the siege.[37]

The experts on the site dated these artifacts to around the early sixth century. This aligns with the siege of Jerusalem in 586 BC. The book of Jeremiah describes the destruction of the city, saying, "He set fire to the temple of the Lord, the royal palace and all the houses of Jerusalem. Every important building he burned down."[38] This paper suggests that the ashen layer discovered on the Mount Zion dig site resulted from the burning of Jerusalem described in Jeremiah. Biblical text further confirms this theory about the findings in Jeremiah 52:15, "Nebuzaradan the commander of the guard carried into exile some of the poorest people and those who remained in the city, along with the rest of the craftsmen and those who had deserted to the king of Babylon."[39] The Babylonians drug the people of Jerusalem from their homes and destroyed their homes. This panic led to the loss of a precious family heirloom. A piece of gold jewelry such as the earring found would be kept within a family for generations. Unless crisis struck, it would not be left behind or in a pile of ash. Therefore, this finding at the UNCC Mount Zion excavation confirms the biblical accounts of the conquest following the siege.

The Siege:

Jerusalem's Fortifications

Jerusalem previously prepared fortifications for coming sieges from Assyria. For that reason, the city possessed many resources to outlast a potential siege, so Zedekiah felt little need for additional fortification. Modern remains of the city walls used can be found in the Jewish quarter. Such as the middle gate, discussed in Jeremiah 39:3, "Then all the officials of the king of Babylon came and took seats in the Middle Gate: Nergal-Sharezer of Samgar, Nebo-Sarsekim a chief officer, Negal-Sharezer a high official and all the other officials of the king of Babylon." The remains of the gate highlighted in this passage allow historians to speculate about the city's fortifications.[40]

The portion of the gate remaining is an "L" shaped wall.[41] The wall itself sits just under five meters thick. The stone-constructed gate would have been built up into a defensive tower. Archers watched for potential threats while positioned atop these towers. Historians find towers such as this across many fortified cities at the time. For example, one Historian described the city of Ashkelon as having "as many as 50 towers on its land side."[42] Being a similarly sized city and being prone to sieges, one could then extrapolate that Jerusalem possessed similar fortifications. With towers positioned every 20-30 meters. These towers created a formidable defensive structure when coupled with the geographic advantages the city already possessed.[43]

The Hinnom and Kidron Valleys additionally fortified the southern and eastern walls. To breach this, the Babylonians needed to create a siege ramp so that the siege works could reach the wall. This paper suggests that Babylonians did not assault these walls because of the lack of evidence of siege ramp construction. In a previous assault, the city fortified its western wall beyond the other three walls.[44] For this reason, it is unlikely that Nebuchadnezzar II attacked from the west. This leaves the northern wall as the weakest point and most likely the one that received the brunt of the Babylonian assault.

The Gihon spring lay outside the city walls and acted as a key water source for the entire city. The city fortified the spring previously for the Assyrian siege in 701 to prevent attackers from accessing the spring. Then Jerusalem engineers dug the Hezekiah tunnel under the wall to access the spring. This spring supplied the city with a stable water supply throughout the two-year siege.[45] For these reasons, the only limiting factor within the fortifications was the food supply and the need to defend the northern wall properly.

Babylonian Armaments

Despite no evidence of siege ramps, Ezekiel 17:17 says, "Pharaoh with his mighty army and great horde will be of no help to him (Zedekiah) in the way, when ramps are built and siege works erected to destroy many lives."[46] With no clear remains of a siege ramp, this verse likely refers to the creation of small mounds to be used as siege ramps that someone later removed or that the Babylonians used as some form of temporary siege ramp substitute. However, in alternate translations, this text is translated as "casting up mounts, and building forts, to cut off many persons."[47] So, with this in mind, it likely referenced the Babylonians laying the groundwork for siege towers and armaments.

Assaulting armies built siege structures on location because the armies understood the impracticality of traveling with the structures. In most scenarios, the assaulting force used local resources to build the structures. With the past few sieges occurring with the use of siege towers in Jerusalem, the area likely possessed local wood that assaulters used for construction. "The towers were probably assembled beyond the range of the defenders' fire and only brought close to the wall later."[48] At the time, engineers referred to the siege structures as nēpešu. The nēpešu were flammable and slow to transport.[49]

Based on an analysis of adjacent sieges, one can expect that Nebuchadrezzer surrounded nearby outposts of the city to cut off resources. In the siege of Lachish, a neighboring city destroyed in Nebuchadnezzar's campaign of 587 BC, Nebuchadnezzar II employed a similar tactic to eliminate their communication and supply lines. Once this entrapment was complete, Nebuchadnezzar II began his assault on the city.[50]

Twenty Months Trapped

Accounts put the siege at just under two years. Jeremiah 39:1 puts the beginning of the siege in the tenth month of the ninth year of Zedekiah's reign.[51] The breach of the walls was dated as the ninth of Tammuz of Zedekiah's eleventh year.[52] Tammuz occurs in June and July. With the conquest of the temple that occurred a week later, August 5, 587 BC, you can place the time of the breach in late July. The siege would have been around 20 months in length. The Babylonians needed to complete their

construction of siege works and the tightening of the supply lines before they fully assaulted the walls.[53]

With intentions of strangling the city's supplies, Nebuchadnezzar II strengthened his hold around the city and cut off communications with allies within the first few months. The city fell to a weakened state of famine and hunger.[5] Then the Babylonians breached the walls, and Nebuchadnezzar requested to meet with Zedekiah to discuss surrender.[55]

Calm before the Conquest

After the two-year siege, the Babylonians breached the wall. However, they waited a month before burning and pillaging the city. Donald Wiseman suggests that this pause resulted from attempts at brokering peace.[56] As previously stated, he based this claim on Jeremiah 39:3, which mentions the gathering of all of Nebuchadnezzar II's officials at the north gate of Jerusalem.[57] See the illustrations section for a period-accurate map of Jerusalem that shows the potential location of this gate. However, when viewed in context, these verses point to a different interpretation of the month pause.

Wiseman's theory confirms the biblical accounts that suggest unrest within the population. However, the struggle of the population existed separate from the negotiation. Jeremiah 37:21 in the KJV says, "Then Zedekiah the king commanded that they should commit Jeremiah into the court of the prison and that they should give him daily a piece of bread out of the bakers' street until all the bread in the city were spent. Thus Jeremiah remained in the court of the prison." Wiseman refers to this verse as evidence of hunger and famine. He felt that this great famine and struggle resulted in the negotiations that caused the month-long armistice. The verses describe the destitute situation within the city during the siege. Jeremiah makes it clear that beyond hunger, people experienced plague, pestilence, and famine.[60]

The month-long delay instead resulted from the pursuit of Zedekiah. The verses following Jeremiah 39:3, which Wiseman cited, give insight into this.[61] When Zedekiah saw that they had gathered at the north gate, he fled with his soldiers out of a southern gate. This is seen in Jeremiah 39:4, "when Zedekiah the king of Judah saw them, and all the men of war, then they fled, and went forth out of the city by night, by way of the king's garden, by the gate betwixt the two walls: and he went out the way of the plain,"[62] His escape route led him through a gate to the south of the city near the city of David. From there, Zedekiah fled towards the plains of Jericho, where the Babylonians captured him a month later.[63] This is the reason that there was a delay before the siege. He was caught and taken back to Babylon to be imprisoned. This account refers to all of Nebuchadnezzar's army pursuing Zedekiah and the remaining soldiers. After his capture, the city was destroyed. This theory aligns with biblical evidence and explains Ezekiel and Jeremiah's disdain for Zedekiah. They blamed him for the city's destruction, not just for his initial disobedience but also for his evacuation when Nebuchadnezzar II offered to meet and negotiate diplomatically. By refusing to meet with Nebuchadnezzar II, Zedekiah brought about the utter destruction of his capital city.

Summary and Conclusion

The evidence presented in the previous sections both supports and challenges existing theories of the Babylonian siege of Jerusalem in 587 BC. The findings at the UNCC dig site confirmed the biblical evidence. The sieges of Lachish and Tyre show the methods of siege warfare used by the

Babylonians. This provides the clearest evidence to build a theory for their methods in the Babylonian siege of Jerusalem in 587 BC. Donald Wiseman provided the clearest analysis of the siege events in his work Nebuchadrezzar and Babylon, but his negotiation theory overlooks the biblical context from Jeremiah 39. This evidence contributes to a strengthened understanding of the second Babylonian siege of Jerusalem. With all of this evidence in mind, this section will provide a short summary and timeline of events as they can now be more deeply understood.

Nebuchadnezzar II demanded the destruction of Jerusalem as penance for King Zedekiah's disobedience. He took action against Jerusalem for the second time during his reign as King of the Babylonian Empire, determined for it to be his last. Nebuchadnezzar swiftly mobilized his military forces, which held great experience with siege warfare.[64] This did not take long; they also actively besieged Tyre in the same year.[65] They arrived and began construction of siege works in mid-January of 588 BC.[66]

They formed a blockade around all of the major gates of the city and built fortifications and walls. They cut off outside contact to any small defensive fortifications that Jerusalem may have possessed.[67] The Babylonian engineers built mobile siege towers so that they could roll to the walls from outside of arrow range. The Egyptian forces possibly arrived during this time and caused a level of disruption within construction, but nothing substantial.[68]

Jerusalem's location and prior siege preparations contributed to its strong fortifications. For this reason, Nebuchadnezzar II focused the blunt force of the siege works on the north wall of Jerusalem. Large defensive towers segmented the walls with soldiers and watchmen.[69] The Babylonian engineers likely built the siege towers to a similar height to combat these towers along the walls.

After over a year of continued siege, citizens in Jerusalem began to grow restless as food became more scarce. Hezekiah's tunnel provided a stable source of water, but the siege eliminated all stable food supply entering the city from surrounding farms. The soldiers defending began to waver and grow weary. Jeremiah references this saying, "He is discouraging the soldiers who are left in this city."[70] With a starving population and weakened military force, the first year of the siege successfully primed Jerusalem for surrender.[71]

As the city struggled, few soldiers remained to fight and defend. Then, the Babylonians used their siege towers to apply enough force of arrow fire to the defending towers to allow sappers to reach and undermine the northern wall. The scythian arrowhead found at the UNCC Mount Zion dig is likely a remnant of this exchange of arrow fodder. The wall was breached in the last week of July 587 BC. After this, the Babylonians spent a month tracking down and capturing Zedekiah. His dissent, shown in his failure to meet with Nebuchadnezzar II, influenced his decision to burn the entire city.

This account further strengthens historical understanding of the siege and understanding of the books of Jeremiah, 2 Kings, and Ezekiel. The discoveries at the UNCC excavation demanded additional research to be conducted and the topic of the siege to be revisited. This paper seeks to do so with a focus on the military actions and siege methods used by the attacking Babylonian forces.

This topic could be further strengthened by future research into the lives of citizens within Jerusalem during the siege. Specifically their perceptions of Zedekiah. Further research into siege warfare across civilizations would strengthen this research. Potential methods used at the siege of Jerusalem that the Babylonians chose uniquely for that siege and no others, like the large ramp at Tyre. Future archaeological excavations around the middle gate might provide further evidence of the validity of Wiseman's negotiation theory. There are many ways this topic can be furthered by future research, which would further enrich the historical understanding of Jerusalem. Through deeper study of the old city, a greater understanding can come to light about the siege that led to the fall of the kingdom of Judah.

Notes

1. D. J. Wiseman. Nebuchadrezzar and Babylon, (Oxford: Oxford University Press, 1985), 36.
2. Jeremiah 39 (NIV); Ezekiel 17 (NIV); 2 Kings 24-25 (NIV).
3. James Hathaway, "Evidence of the 587/586 BCE Babylonian Conquest of Jerusalem Found in Mount Zion Excavation" Inside UNC Charlotte. August 12, 2019.
4. Jeremiah 39:1 (NIV).
5. Wiseman, Nebuchadrezzar and Babylon, 37.
6. Wiseman, Nebuchadrezzar and Babylon, 21.
7. Wiseman, Nebuchadrezzar and Babylon, 17, 43.
8. Wiseman, Nebuchadrezzar and Babylon, 23.
9. 2 Kings 23:36-24:4 (NIV); Wiseman, Nebuchadrezzar and Babylon, 22-24.
10. Israel Eph'al, "Military Aspects" in The City Besieged: Siege and Its Manifestations in the Ancient Near East, (Leiden: Brill, 2009).
11. Eph'al, City Besieged, 36.
12. Eph'al, City Besieged, 37.
13. Eph'al, City Besieged, 36-39.
14. Wiseman, Nebuchadrezzar and Babylon, 32.
15. Yosef Garfinkel et al. "Constructing the Assyrian siege ramp at Lachish: Texts, Iconography, Archaeology and Photogrammetry," Oxford Journal of Archaeology Volume, 40. Issue 4.
16. Seen in Fig. I.
17. Yosef Garfinkel, et al. "Lachish Fortifications and State Formation in the Biblical Kingdom of Judah in Light of Radiometric Datings," Radiocarbon 61, no. 3 (June 2019): 695-712.
18. Jacob Katzenstein, The history of Tyre. From the beginning of the second millennium B.C.E. until the fall of the Neo-Babylonian empire in 538 B.C.E, (BenGurian University of the Negev Press. 1997 2nd Edition.): 313-316.
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20. Garfinkel, et al. "Lachish Fortifications and State Formation in the Biblical Kingdom of Judah in Light of Radiometric Datings," 695-712.
21. Alexander Fantalkin, "Why Did Nebuchadnezzar II Destroy Ashkelon in Kislev 604 B.C.E?" *In The Fire Signals of Lachish: Studies in the Archaeology and History of Israel in the Late Bronze Age, Iron Age, and Persian Period in Honor of David Ussishkin*, 102, (University Park: Penn State University Press, 2011).
22. 2 Chronicles 32:2-4 (NIV); also seen in Fig. III.
23. Ezekiel 17:16, 18 (NIV).
24. Ezekiel 17 (NIV).
25. Jeremiah 34:17 (NIV).
26. Jeremiah 34-39 (NIV).
27. 2 Kings 23 (NIV).
28. 2 Kings 25:3 (NIV); Jeremiah 52:6 (NIV).
29. Jeremiah 39:2 (NIV).
30. Wiseman, *Nebuchadrezzar and Babylon.*
31. Wiseman, *Nebuchadrezzar and Babylon, 32.*
32. Wiseman, *Nebuchadrezzar and Babylon, 35.*
33. Wiseman, *Nebuchadrezzar and Babylon, 33.*
34. Hathaway, "Evidence of the 587/586 BCE Babylonian Conquest of Jerusalem Found in Mount Zion Excavation."
35. Hathaway, "Evidence of the 587/586 BCE Babylonian Conquest of Jerusalem Found in Mount Zion Excavation."
36. Seen in Fig. II.
37. Hathaway, "Evidence of the 587/586 BCE Babylonian Conquest of Jerusalem Found in Mount Zion Excavation."
38. Jeremiah 52:13 (NIV).
39. Jeremiah 52:15 (NIV).
40. Jeremiah 39:3 (NIV).
41. Seen in Fig. III.
42. Fantalkin, "Why did Nebuchadnezzar II Destroy Ashkelon in Kislev 604 B.C.E?" 102.
43. Fantalkin, "Why did Nebuchadnezzar II Destroy Ashkelon in Kislev 604 B.C.E?" 91.
44. Wiseman, *Nebuchadrezzar and Babylon*, 37.
45. Nazek Khaled Matty, *Sennacherib's Campaign Against Judah and Jerusalem in 701 B.C.: a Historical Reconstruction*, (Berlin: De Gruyter, 2016).
46. Ezekiel, 17:17 (NIV).
47. Ezekiel, 17:17 (KJV).
48. Eph'al, City Besieged, 97, 100.
49. Eph'al, City Besieged, 97-100.
50. Garfinkel et al. "Lachish Fortifications and State Formation in the Biblical Kingdom of Judah in Light of Radiometric Datings." 699.
51. Jeremiah, 39:1 (NIV).
52. Jeremiah, 39:2 (NIV).
53. Wiseman, *Nebuchadrezzar and Babylon*, 37.
54. Jeremiah, 37:21 (NIV).
55. Jeremiah, 39:3 (NIV).
56. Wiseman, *Nebuchadrezzar and Babylon*, 37.
57. Jeremiah 39:3 (NIV).
58. Seen in Fig. III.
59. Jeremiah 37:21 (KJV).
60. Jeremiah 37:21 (NIV). Wiseman also cites 2 Kings

6:24-7:4 as evidence for starvation in the city walls. These verses refer to the siege of Samaria, conducted by the king of Aram, which led to widespread starvation. This siege is unrelated to the topic at hand.
61. Jeremiah, 39:5-7 (NIV).
62. Jeremiah, 39:4 (NIV).
63. Jeremiah, 39:5 (NIV).
64. Wiseman, *Nebuchadrezzar and Babylon*, 36.
65. Eph'al. "Nebuchadrezzar the Warrior: Remarks on his Military Achievements." 186.
66. Wiseman, *Nebuchadrezzar and Babylon,* 36.
67. Wiseman, *Nebuchadrezzar and Babylon,* 37.
68. Wiseman, *Nebuchadrezzar and Babylon*, 37.
69. Fantalkin, "Why did Nebuchadnezzar II Destroy Ashkelon in Kislev 604 B.C.E?" 91.
70. Jeremiah, 38:4 (NIV).
71. Jeremiah, 37:21 (NIV).

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Appendix A

Figure I, Assyrian sappers undermine walls of Lachish Neo-Assyrian. Siege of Lachish (Judah): *Assyrian Sappers Undermine the City Walls, Detail [L.] of Relief from SW. Palace of Sennacherib at Nineveh (Kuyunjik),* n.d

Appendix B

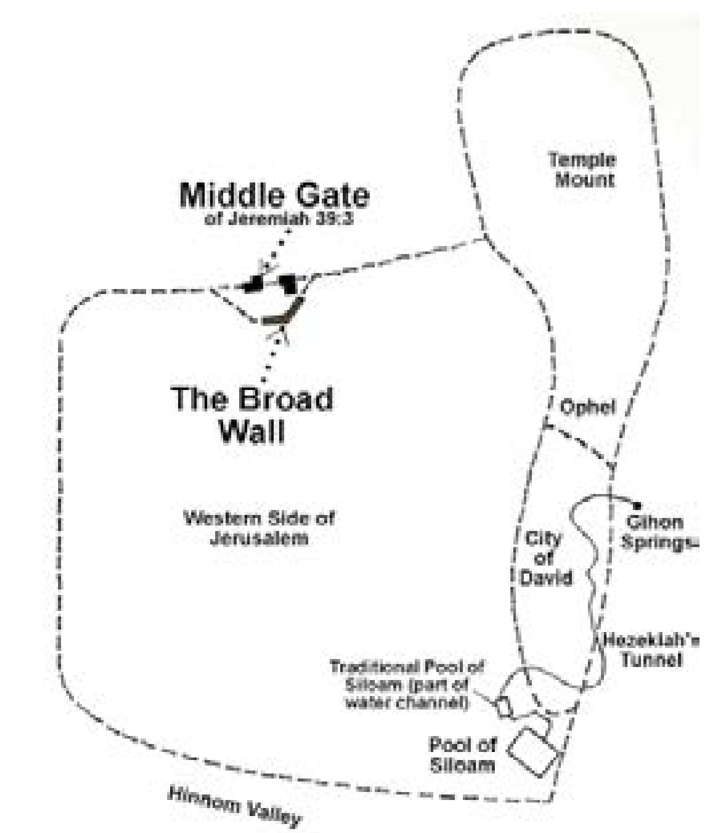

Figure III, Placement of the Middle Gate on a map N/A. "26- The Middle Gate (of Jeremiah 39:3)." Jerusalem 101, 2022. https://www.generationword.com/jerusalem101/26-middle-gate.html

Appendix D

Figure IV, Period-accurate map of Jerusalem in Red *Jerusalem: Map: Period of Solomon and Hezekiah, c.996-c.586 B.C.E.* n.d. Visual Arts Legacy Collection. Artstor. https://jstor.org/stable/community.18136174.

The Phone as a Tool in Modern Black Self-Defense

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Abstract: As Black Americans continue to be targets of police brutality and racial discrimination, the phone has evolved into an effective tool for Black self-defense. This paper examines the ways in which ideas of black self-protection have persisted and evolved over the past two decades. While many historical notions of Black self-defense have persevered, the emergence of social media and technology in activism has led to a new form of Black protection. Utilizing a variety of primary and secondary sources, this paper examines the history of Black Self-Defense, nonviolence versus militancy, and using social media in activism, particularly in Black liberation movements. In recognizing the phone as an effective weapon in combating racial discrimination, Black Americans can utilize this tool to protect themselves, get justice for others, and prevent future recurrence.

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Keywords: racial discrimination, digital activism, black historiography, videography

Introduction

On May 26, 2020, organized protests around the world erupted following the widespread circulation of a bystander video that captured the murder of George Floyd. The 10-minute video, recorded by 17-year-old witness Darnella Frazier, was posted to Facebook and Instagram shortly after the murder took place. A statement released by Frazier's lawyer stated, "I opened my phone and I started recording because I knew if I didn't, no one would believe me."[1] Frazier's video served as an important catalyst in the emergence of the George Floyd protests and acted as crucial evidence in the trial of the perpetrator, Derek Chauvin. Although the video documenting the incident did not change Floyd's fate, it did ensure that his story did not go unnoticed. The civil unrest immediately following George Floyd's murder was unprecedented, resulting in extensive conversations about systemic racism globally and calls for significant criminal justice reform.

In documenting and circulating instances of racial discrimination, the phone acts as a tool for Black individuals to protect themselves, get justice for others, and prevent future occurrences from taking place. This paper examines the ways in which ideas of Black self-defense have persisted and evolved over time, with a particular focus on the 21st century, distinguishing between which ideas and practices are strictly for safety and which are used as a form of rebellion against racial discrimination. Specifically, this paper argues that while many historical ideas of Black self-defense have endured, the emergence of social media and technology has resulted in a major shift in the ways in which it is practiced.

Historiographical Section

One of the most contentious characteristics within the civil rights movement, as well as subsequent movements, was the practice of armed self-defense. Civil rights scholar Charles E. Cobb argues that while Dr. Martin Luther King, Jr. is well-known for his nonviolent tactics, guns played a major role in the fight for racial equality during the Civil Rights Movement.[2] In *We Will Shoot Back*, Akinyele Omowale Umoja asserts that Black Southerners used armed resistance to challenge White supremacy intimidation tactics and successfully preserve Black southern communities.[3] In an attempt to reconcile nonviolence and militancy, scholar Simon Wendt presents two distinct ideologies present in the Civil Rights Movement and subsequent Black Power Movement: protection versus revolution.[4] Wendt argues that the idea of nonviolence was utilized as a tactic for protection, and the addition of weapons grew out of necessity rather than as a sign of rebellion.[5] On the other hand, Wendt argues that militant groups used armed self-defense tactics in a more symbolic manner which ultimately proved less effective than nonviolence; for instance, Wendt argues that Black Panther Party members used armed resistance as a gendered symbol to affirm Black masculinity.[6] While most scholars acknowledge the importance of Black self-defense in 20th-century Black liberation movements, a consensus on the relationship between nonviolence and armed protection proves to be elusive.

In broader literature, photography has long been used as a tool of resistance in documenting and circulating images of political and social struggle. Documentary photography has played an important role in raising awareness and preserving the legacy, both favorable and unfavorable, of significant figures and movements in history. Referred to as the first television war, the Vietnam War was a turning point for many Americans regarding public sentiment on violent conflict largely due to the visual testimonies which illustrated civilian suffering. One enduring image from the Vietnam War era, dubbed "Accidental Napalm," depicts a naked girl screaming in pain from napalm burns covering her body. While the image itself was horrifying, it transcended an individual experience, instead symbolizing the immoralities of war. Similarly, images of Nazi Germany continue to shape our memories and memorialization of the Holocaust. However, in *Through Amateur Eyes: Film and Photography in Nazi Germany*, author Frances Guerin challenges the iconic imagery of the Holocaust, arguing much of it comes from Nazi perpetrators and sympathizers. Rather, Guerin focuses on the amateur photography of the era taken by soldiers, resistance workers, and civilians, ultimately asserting these images are more impactful as they show impromptu, everyday depictions of life in the face of trauma and loss. These famous examples of documentary photography display the power and influence that images can have on society, acting as a tool that can garner attention and sway public opinion on civil conflict.

While the concept of social media being a modern tool for Black self-defense has not fully been explored, many scholars have discussed the efficacy of social media as a tool for activism. In *Making All Black Lives Matter*, historian Barbara Ransby notes that the Black Lives

Matter movement, the most prominent Black liberation movement of the 21st century, started with a hashtag on a Facebook post regarding the acquittal of George Zimmerman, the perpetrator in the shooting of Trayvon Martin.[10] Providing multiple examples of social media use in the movement, Ransby ultimately argues that the use of social media as a tool for activism is a viable path toward an equitable society.[11] In *The Prophetic Lens*, Phil Allen provides the most comprehensive connection between historical ideas of Black self-defense and modern technology.[12] Allen claims that the camera has been a powerful tool in both past and modern black liberation movements, maintaining that the camera even played a major role in the Civil Rights Movement as leaders such as Dr. King wished for everything to be filmed and photographed.[13]

Early Ideas of Black Self-Defense

Given the nonviolent tactics of the Civil Rights Movement, this period reveals many early thoughts and manifestations of Black self-defense. In his book of oral history, *My Soul is Rested*, Howell Raines provides first-hand accounts from a variety of prominent activists in the Civil Rights Movement from 1974 to 1976.[14] One interviewee was Hartman Turnbow, a grassroots civil rights activist who was one of the first African-Americans to attempt to register to vote in Mississippi. In his account, Turnbow recalls an incident in May 1963 in which he was targeted by two white assailants who set his house on fire and shot at him, to which he responded by firing his own weapon.[15] Upon meeting Dr. King, Turnbow challenged his stance on violence, stating, "This nonviolent stuff ain't no good. It'll get ya killed...If [the white man] pose with a smile, meet him with a smile, and if he pose with a gun, meet him with a gun."[16] He further explained that the bravery that he felt came from his love for his family and his desire to protect them at all costs. Turnbow justifies his actions, despite pushback from Dr. King, as he believes that he has a right to respond to violence with violence.

While civil rights leaders attempted to reconcile nonviolent tactics with armed protection, the Black Panther Party (BPP) embraced dangerous confrontation. Between early 1967 and late 1968, the BPP established patrols of police in an effort to capture police misconduct incidents. In Black Against Empire, Joshua Bloom and Waldo E. Martin describe one of these patrols in early 1967 Oakland involving BPP founders Huey Newton and Bobby Seale as well as Lil' Bobby Hutton, the first party recruit.[17] While they were monitoring a police car, the three men caught the attention of an officer as their firearms were clearly visible. After the officer pulled them over and attempted to take the weapons, Newton refused, exclaiming, "Ain't you ever heard of the Fourteenth Amendment of the Constitution of the United States? Don't you know you don't remove nobody's property without due process of law?"[18] Educated on firearm laws and constitutional rights, Newton and Seale used this initial tactic to draw attention to police misconduct, thereby attracting additional party members through street discussions. BPP members also took advantage of the press as authorities pushed back on their practices. On May 2, 1967, 30 armed BPP members arrived at the capitol building in Sacramento, challenging police who attempted to take their weapons before reading a statement in front of reporters regarding the Mulford Act, which sought to limit their armed demonstrations.[19] Though unsuccessful in obstructing the passage of the legislation, the BPP demonstrated that weapons were not the only effective tool in combating racism.

In addition to patrolling the police, the BPP consistently advocated for Black people to arm themselves for protection against likely attacks. In the May 4, 1968 edition of *The Black Panther Party* newspaper, a column titled "Arm Ourselves or Harm Ourselves" describes that "White citizens are arming themselves all over the country and organizing their communities not for self-defense, but for the outright slaughter of innocent Black civilians."[20] Citing multiple specific examples, such as the city of Newark purchasing shotguns and rifles for its police department, this column implies that the BPP is advocating for its followers to arm themselves as they believe White citizens are preparing to harm the Black community.[21] In contrast to Hartman Turnbow, the BPP advised its readers to be proactive in preparing to defend themselves, while Turnbow and other civil rights activists waited until they were targeted or attacked to fight back. However, while the nonviolent Civil Rights Movement has a seemingly different viewpoint than the militant BPP, this column also bears many similarities to Turnbow's justification of his act of self-defense. This volume further expands on early ideas of Black self-defense, building off of civil rights ideologies and advising followers to be prepared.

Modern Examples of Black Self-Defense

Contemporary examples of police brutality can reveal the power of phone recordings as a tool for Black self-defense. On April 4, 2015, a 50-year-old Black man, Walter Scott, was fatally shot by a police officer, Michael Slager, after being stopped for a non-functioning brake light.[22] Initially, Slager claimed that Scott had taken his taser and that he felt threatened, which led him to shoot Scott.[23] However, a video recorded by bystander Feidin Santana contradicted Slager's story, as the video depicted an object falling to the ground and Scott running away before being shot in the back eight times.[24] Santana states he was hesitant to come forward with the video and feared retaliation, but upon reading the police report, he knew that Officer Slager's story was misrepresentative of the situation.[25] Santana notes, "...the police officer just shot him in the back. I knew right away, I had something on my hands."[26] This quote illustrates the use of the bystander recording as a tool to get justice for Walter Scott as Slager likely would have gone without punishment had the video not been recorded. Santana's explanation demonstrates how a phone recording is not just used as evidence, but rather as a tool for protection and justice.

Although phone recordings have often been utilized in instances of police brutality, the phone can also be used in self-defense in everyday occurrences of racial discrimination. Anthony Gibson, a Black man who frequently posts about his fishing experiences on his TikTok, began videotaping instances where he was confronted by his white neighbors for fishing at the private community's lake.[27] In a TikTok video posted on July 11th, a White woman, Tanya Petty, can be seen approaching Gibson who is accompanied by two Black female friends.[28] Petty proceeds to question whether Gibson and his friends are residents of the neighborhood, stating the lake is reserved for residents only.[29] Despite being a resident in the neighborhood and having a permit to fish, Gibson notes, "Literally every single time I went fishing, someone bothered me. That's the only reason why I turned the camera on."[30] As the neighbors who confront him often end up calling the police, Gibson adds that "If you call the police on a Black man, there's already some suspicion,"[31] suggesting that he viewed these encounters as having the potential to escalate into a dangerous situation. Ultimately, Gibson's posts provide an example of the way the phone can be used as a tool for self-defense in everyday instances of racism.

While some may argue that recording police or other discriminatory confrontations is purely to have evidence, video recordings represent an act of expression and resistance. Jocelyn Simonson, Professor of Law at Brooklyn Law School, discusses the recent pushback on filming the police, framing it as an act protected by the First Amendment. Simonson describes the history of organized copwatching groups where residents observe and document police activity to watch for potential misconduct.[32] She argues that "you cannot hold up a camera in front of a police officer without it being a political act or an act of dissent."[33] This quote supports the argument that the use of the phone in Black self-defense goes beyond providing evidence for legal cases but is also a way to resist discriminatory experiences. With this reasoning, filming the police would be unquestionably protected by the First Amendment, which is especially relevant as recent court cases have argued that documenting the police is not a constitutional right. This is compounded by the fact that police body camera footage is often difficult for the public to obtain access to. These arguments could suggest serious consequences for modern Black self-defense, as the use of the phone as a tool for protection and resistance may be under attack by legislators. Though these potential restrictions could pose a risk for Black Americans seeking justice, the parallels to past legislative control of the BPP's armed demonstrations strengthen the argument that the phone is a modern means of confronting systemic racism.

Conclusion

As Black Americans continue to be targets of police brutality and racial discrimination, the phone has evolved into an effective tool for Black self-defense in allowing Black individuals to protect themselves, get justice for others, and prevent future recurrence. Early movements, such as the Civil Rights Movement and Black Power Movement, differed in their stances on nonviolence and revolution, though most activists saw the value of armed protection. In recent times, scholars have acknowledged the value of digital activism as social media has provided an outlet for advocates to document and disseminate recordings of racially unjust incidents. Though existing literature seldom integrates the potential of modern technology into analysis of historical Black self-defense tactics, this paper hopes to address this deficiency by connecting enduring ideas of Black liberation, famous documentary photography, and contemporary innovation.

Further consideration of the phone as a tool in modern Black self-defense is especially critical in today's social climate as anti-DEI legislation is on the rise, reversing many programs and initiatives that were in place to protect the Black community and other marginalized groups. Future research could also examine various populations, such as women resisting sexual harassment or immigrants navigating increased ICE threats. As advancements in technology have made the world more connected, recognizing the phone as a tool to combat racial discrimination, and other forms of discrimination, is an essential step in progressing toward a more equitable society.

Notes

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