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EXPLORING DIFFERENT MEDIUMS FOR TEACHING PROGRAMMING AND CYBERSECURITY IN PRIMARY AND SECONDARY SCHOOLS

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By

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List of Abbreviations

STEM – Science Technology, Engineering, and Math

3D – 3-Dimensional

GCS – Ground Control System

DoS – Denial of Service

ESC – Electronic Speed Controller

OS – Operating System

k-12 – Kindergarten to 12^{th} grade

ssh – Secure Shell

noVNC – noVirtual Network Computing

API – Application Programming Interface

SDK – Software Development Kit

AI – Artificial Intelligence

CIAAN – Confidentiality, Integrity, Availability, Authentication, and Non-Repudiation

Abstract

Cybersecurity and programming are becoming more and more prominent in today's world. It is beneficial to begin teaching these topics to students at a younger age. Additionally, we see students in primary and secondary schools struggling to maintain focus in class as attention spans shrink. This paper looks at different drone models to see if any of them could be sufficient solutions to be implemented into primary and secondary schools to teach cybersecurity and programming topics to students. Besides teaching capabilities, drones must also be affordable for institutions and simple enough to construct, configure, and operate so that a teacher with little knowledge could implement the drone if needed. The drone models looked at are a custom-built Raspberry Pi Pixhawk Quadcopter from Drone Dojo, Dexter Industries' GoPiGo, and DJI's Mavic Air 2. Additionally, we look at different teaching methods and activities that can be implemented into a curriculum outside of drone use. Curriculum was created for different programming and cybersecurity courses and tested during the 2022 GenCyber summer camp hosted by Michigan Technological University. This curriculum gives us an insight into teaching middle and high school students cybersecurity, artificial intelligence, and Python coding. The thesis of this paper is that the GoPiGo is an effective medium for teaching programming in primary and secondary schools, and that hands-on activities are successful in reinforcing taught topics while keeping students engaged.

1 Background

1.1 Drones in Industry

Drones are becoming more and more prevalent in today's world both professionally and commercially. A drone is defined by The Corona Wire [2022] as a "remotely operated, autonomous, or automated robot that is capable of sensing information, processing it, and executing a physical action that changes something in the world without a pilot on board". Often used for efficiency or tasks deemed too dangerous, dirty, or monotonous for humans [1], drones are being implemented into a wide variety of industries across the world. In agriculture, drones can be used to spray fertilizer and monitor plants, being able to detect individual crops amongst a large field that may need individualized care. In the medical field, drones can transport important components much through the air much quicker than traditional ground transport if needed. In the aircraft industry, drones have been implemented to complete aircraft checkups required before each flight [23]. Despite the continued integration of technology such as drones in almost every industry, in the United States, the supply of professionals trained in STEM related careers does not fill the demand for them [17]. With drones being used in popular industries, it can be a great benefit for students interested in pursuing any career path to have experience using them.

1.2 Issues in Learning Today

For students across the country, it seems that expectations and the levels at which they feel achievement are rising, while their patience for learning and attention spans are falling. This further creates a challenge in finding a balance between implementing new technology to keep students intrigued while avoiding shrinking the amount of useful acquired knowledge that is necessary for long term achievement. Researchers have concluded that a main part of young students' lives rely on staying connected with technology that they are taking for granted [4].

In terms of implementing programming classes into elementary school's curriculum, many institutions lack the materials and methods necessary to properly teach them. It can be difficult to know what materials are necessary for each school as they vary in size, student ability, teacher ability, financial resource, and availability in the curriculum [24]. A smaller institution may not be able to hire a teacher with the appropriate skillset to teach a course effectively or have the funds to buy the required teaching materials. The methods needed to teach a course vary between large and small schools that have different class sizes. Even with all materials and methods available, some schools may not have any space to implement an additional course into a student's curriculum, leaving them with a challenge of deciding what course to replace.

In Japan, many schools have implemented programming classes using an easy to learn, beginner programing language, Scratch. In these courses there are common problems that have been observed. Young elementary school students get tired of sitting still in classes that only use desktop computers. These students also lack the ability to collaborate with one another and take a proper initiative during these classes [24].

1.3 Benefits of Drones in Education

1.3.1 Improving Student Motivation to Learn

Using drones in teaching increases the attention spans of students [4]. It has been shown that middle school programming classes that use robots increases a student's interest and the educational effect of the class overall. A study was done that ran programming classes for elementary school children using drones. The study saw that young students can easily create programs while understanding what they are doing. Flying the drone using a program the student had created gives that student a sense of accomplishment. The study found that the students who took the course were very interested in the topics and were motivated to learn more, wanting to take another programming class that used drones. Even parents of the students were very interested in what their children were learning, wanting to buy the drone used in the course [24].

1.3.2 Developing Technical and Nontechnical Skills

Using drones allows for more advanced learning than traditional programming classes using exclusively desktop computers [24]. This helps development many different skills, both technical and nontechnical skills. Saiki et al. [2021] saw that young students understood sequential elements in programming and were even able to use unlearned topics, such as 3D coordinates, that helped promote collaborative learning [24].

Using drones alongside education develops a student's creativity, imagination, active learning, and problem-solving skills. Proper implementation of this allows for a student to understand and apply what they are learning. It was also shown that this method positively affects their ability to learn independently, implement hands-on learning attitudes, and apply innovative thinking while improving their attitudes toward problem-solving. Additionally, students can also recognize and apply proper flight ethics [9].

1.3.3 Cross-Domain Learning

To extend beyond programming, drones can be used as a medium to implement cross-domain learning [9]. STEM areas often line up to allow a student to learn about topics such as flight, civil engineering, natural resources, and agriculture through proper implementation into lessons [17].

Saiki et al. [2021] suggested that drones can be used to teach content typically difficult to understand for a student at their level. This was seen in the ability of elementary school students to implement 3D coordinates, which are not taught until after elementary school, to program a drone to fly through an obstacle course [24].

Another study used a quadcopter drone to explain the math and physics behind its flight while keeping the students' interest. Harnessing a student's excitement to implement their learning and fly the drone allows the student to understand the math and physics concepts behind the kinematics more easily than the traditional math or physics lecture, which can struggle to hold a student's attention [4].

1.3.4 Connecting to the Future

Farr et al. [2019] designed a curriculum implementing STEM with goals of linking a student's interests and future goals to real life careers and teaching current skills and problem-solving strategies to prepare students for a future in STEM. Linking student interests and goals to careers can increase their motivation to learn, leading to academic success. The curriculum hopes to apply contextual learning to show the connection between learning and possible career goals. Using drones as the medium for the curriculum allows STEM to be taught while drawing direct connections to different career pathways within STEM itself [17].

1.4 Cybersecurity in Drones

Cybersecurity is a rapidly growing area that can benefit from students beginning education earlier. Drones can potentially be a strong medium for jumpstarting students' cybersecurity education. There are many different types of attacks depending on the part of the system that is targeted, allowing for students to analyze the attacks in a more hands on way.

1.4.1 The Drone System

A drone system is made up of three main parts: the drone, the ground control system (GCS), and the communication link. The drone contains the flight controller which is the central processing unit of the drone. The flight controller helps guide a drone throughout its flight, reading data from the drone's sensors and adjusting accordingly, and establishes the communication link to the GCS. The GCS typically references the remote transmitter a pilot uses to command the drone, but on a larger scale, the GCS could be an entire facility. The GCS sends commands to and receives data from the drone. This communication occurs via the communication links, which are the wireless connections between the drone and the GCS. The link is typically made through direct radio waves, but on a larger scale, the link could be made using satellite communications. Drones used for teaching students typically will be using direct radio waves for their communication links [1].

1.4.2 Attacks on the Flight Controller and GCS

An inflight drone relies heavily on its multiple sensors to remain stable. The GPS of a drone can be jammed or spoofed. The transmission of the drone can also be jammed or spoofed to take control of the drone and change its course. Spoofing attacks can change the data sent from the flight controller to the GCS to change the pilot's commands by making them think the drone is acting in a way that it is not. Every external sensor on a drone can be manipulated to falsify its sensor data to destabilize the drone [1].

1.4.3 Attacks on the Data Link

An attacker can gain unauthorized access to the communication link to see data from the drone or commands from the GCS and act accordingly. A DoS attack can be used to prevent the GCS and drone from communicating. The GCS control signals can be spoofed to enable a man-in-the-middle attack or covert wireless injection attack [1].

1.4.4 Cybersecurity Implementations for a Drone

A drone's communication device can contain an encryption function which allows all data being transmitted from the drone to be encrypted to prevent unauthorized access. This encryption can be implemented in both the software and hardware of the drone [19]. To prevent GPS jamming, alternate methods of navigation on your drone can be implemented. This allows for the drone to continue flight if it notices no incoming data from the GPS. GPS signal authentication can be used to prevent GPS spoofing. Similarly, authentication can be implemented for communications between the GCS and the drone. Applying continuous mutual authentication between the drone and pilot throughout the communication is necessary. Digital signatures can be used to bind the pilot to their drone for authentication [1].

2 Methodology

We evaluated and compared three different types of drones for use in primary and secondary school environments. To evaluate their effectiveness, we look at their cost, ease of setup, ease of operation, ease of integration, programmability, ability to be victim of different cyberattacks, and ability to implement cyber solutions. The cost includes the cost of the drone kit as well as any additional equipment needed for construction or operation. We ask if the cost of the kit would be reasonable to expect institutions of any size to be able to afford.

The ease of setup looks at the complexity and time commitment to complete both the drone's construction and configuration. We ask if it could be expected of a school's staff to set up all purchased kits together in a reasonable manner. The ease of operation looks at the complexity of controlling the drone including any software needed, if applicable. The ease of integration looks at the overall ease of use to see if an average teacher could reasonably implement the medium into their curriculum.

A drone's programmability is measured in its ability to be controlled autonomously via a student's code. It also looks at the ability to use different levels of programming including block programming for beginners up to standard programming languages such as Python or C. To appropriately teach cybersecurity a drone must be able to cover the topics in a reasonable manner. This could include its ability to be the victim of different common cyberattacks or to implement common cyber solutions onto each drone. The attacks and solutions used should meet the ones taught to students within the curricula using drones as a medium to reinforce the topics.

With regards to GenCyber and the methods it implements throughout the summer camp, a daily Google Form was filled out by each student. Each form contained three questions that gathered the student's understanding of the topics for that day. Three open-ending questions were also asked to gather what students were interested in, what they didn't find useful, and if they had any suggestions for the camp.

3 Pixhawk Quadcopter

3.1 Setup

3.1.1 Acquisition

The Pixhawk Quadcopter came in a drone kit available online from the Drone Dojo for $899. Each kit includes a Raspberry Pi 4B, a Pixhawk Flight Controller, and all parts necessary for the physical and electrical construction of the drone [5]. Two drone kits were purchased from Drone Dojo for this research.

3.1.2 Construction

The drone kit comes with step-by-step setup videos, but many are outdated using old components or following different steps for calibration. The Pixhawk Quadcopter requires soldering to connect the electronic speed controllers (ESCs) to the frame. The construction was not beginner friendly, expecting the individual constructing to understand all the electronic components and know how to solder. Also, the drone kit did not come with an M1 Allen wrench, which is required to secure the GPS module to the frame. The kit did however include an M2 and M3 Allen wrench.

It took some time to acquire the missing Allen wrench as well as find someone confident in their soldering abilities. General construction of the physical drone took around five hours.

3.1.3 Electronics Calibration

The calibration process included setting up the Raspberry Pi, calibrating the remote transmitter to the receiver, and ensuring that the drone can connect to the flight software selected by the user. Configuring the Raspberry Pi has its own video provided with the drone kit. Once the flight software is connected calibration can being on each individual component including the gyroscope, GPS, remote transmitter, and the ESCs.

The Pixhawk Quadcopter has 4 ESCs, one for each motor. The ESCs ensure that each motor spins at the same speed at the same time for a stable flight. Calibrating the ESCs was the most time-consuming step of calibration. The purchase of the drone kit also granted access to an online forum as well as the email of Drone Dojo's Founder for any direct questions. Using the forum, the Pixhawk documentation available online, the provided step-by-step videos, and the founder's email, different ways to calibrate the ESCs were identified. Emailing the founder of Drone Dojo provided some help in calibrating the ESCs. After many attempts, the ESCs are believed to have been correctly calibrated only a few times, but never did the final product instill confidence that would lead to a stable flight. Calibration should only need to be performed once at the initial setup of the drone. Calibrations for the Pixhawk Quadcopter took around 15 hours.

3.2 Flight

Flying the Pixhawk Quadcopter was done using Mission Planner [2]. The software can be complicated to understand for an inexperienced pilot. All prechecks must be done before flight is able to be conducted. Mission Planner allows for a lot of advanced capabilities including route setting and autonomous flight.

Between the two Pixhawk Quadcopters setup, only one was able to get into the air. The drone shakily hovered in Stability mode with Mission Planner with a drift to the left. Emailing the founder, he said that could be expected in Stability mode. Overall, completing the steps from calibrating the components to performing the drone's initial flight took around 10 hours.

3.3 Discussion

3.3.1 Pros

The Pixhawk Quadcopter allows for programming through the Raspberry Pi as well as implementation of cybersecurity through many areas. Mission Planner allows for autonomous flight and many ways to customize and adjust the drone's methods of flight.

3.3.2 Cons

The Pixhawk Quadcopter is costly at $900 for the kit [5]. It requires some knowledge in electronics, a soldering iron and M1 Allen Wrench that was not included, and knowledge on how to solder. Construction and calibration of the drone takes a large amount of time with total time spent equal to around 30 hours. There is also a learning curve to understanding the Mission Planner software as it can be overwhelming at first glance.

3.3.3 Conclusion

In terms of use in primary and secondary schools, the Pixhawk Quadcopter would be a poor fit for teaching programming and cybersecurity. It accomplishes both goals of being programmable and being able to apply cybersecurity implementations, but falls short with the price, need for prior knowledge, learning curve of software, and time to setup for use. Small to medium-sized institutions may find it difficult to supply the resources to acquire even a couple of drones to be shared among many students at $900 a unit. The cost increases when considering the additional tools and time required for the school's staff to setup the drones and learning the software to prepare for implementation into the classroom. All in all, the Pixhawk Quadcopter is not recommended for use in primary and secondary schools to teach programming and cybersecurity.

4 GoPiGo

4.1 Setup

4.1.1 Acquisition

The GoPiGo kit is sold by Dexter Industries and costs $249. The kit includes a Raspberry Pi 3B+, the robot chassis and electronic board, a micro-SD card preloaded with the GoPiGo operating system, a USB thumb drive, a rechargeable battery, a distance sensor, a servo package, and a mount for the distance sensor or a camera. Also available, is the GoPiGo for Groups bundles that includes 5 GoPiGo kits as well as 15 grove LED lights, 15 sensor mounts, and a spare parts kit, for $1309 [11]. One standard GoPiGo kit was used for this research.

4.1.2 Construction

The GoPiGo took around 30 minutes to construct. The kit comes with clear step-by-step picture instructions that are very easy to follow. All tools necessary for construction were included and there are easy to follow videos on the website [10]. The GoPiGo kit includes a micro-SD preloaded with the GoPiGo operating system developed by Dexter Industries. Launching the Raspberry Pi with the micro-SD card inserted will boot into the OS automatically.

4.2 Operation

Once the GoPiGo is connected to the network, the GoPiGo board emits its own wireless network to connect via a laptop or tablet. Once connected, the user can control the GoPiGo from their laptop or tablet by connecting to the Apache webpage hosted by the Raspberry Pi at the default site, dex.local. The webpage has many options for control including direct control, block programming, and advanced programming using Python or other languages.

Direct control allows the user to operate the GoPiGo pressing the corresponding buttons displayed on the connected laptop or tablet. Block programming allows the GoPiGo to use the distance sensor that comes with the kit and do basic programming in easy to understand drag and drop. This kind of programming is especially useful to start younger students on learning the basics while taking the GoPiGo through fun activities such as obstacle courses. As students grow and get more comfortable with block programming, they can next move to actual programming through languages such as Python.

4.3 Discussion

4.3.1 Pros

The GoPiGo is an affordable option for anyone trying to get into programming and robotics. It is incredibly easy to setup and operate, allowing users to be operating in less than an hour. The application of the GoPiGo to begin educating k-12 students in programming is widely seen. The GoPiGo website talks widely about the many uses

GoPiGos can serve in education. There are many affordable projects that bring add-ons to the GoPiGo, including cameras, sound sensors, light sensors, and more [11].

4.3.2 Cons

The GoPiGo is very insecure cybersecurity wise. The operating system was designed insecure for ease-of-use for users. This creates a challenge when it comes to implementing any cybersecurity solutions and thus teaching students' cybersecurity. Dexter Industries has also created an operating system called Raspbian for Robots based on Raspbian Buster (a Raspberry Pi OS legacy). This allows you to be able to access the system and customize it via command line in ssh, through noVNC, or directly wired into the Raspberry Pi. There are some cybersecurity standards that can be implemented that also teach students how the system operates. This includes updating the Apache webpage to HTTPS and creating an authentication page, so it does not automatically log in the user when connecting through ssh. However, this can prove above younger students' abilities.

Another issue with the GoPiGo is its operational limitations. Although capable of a lot, the GoPiGo ultimately is a slow-moving ground robot. Older students may get bored after a few of the projects, especially if the school is unable to continue to purchase new parts for new projects. However, the GoPiGo can work with Google's Cloud Vision API to explore more advanced areas of computer science that could keep older students with programming experience engaged [11].

4.3.3 Conclusion

In terms of use in primary and secondary schools, the GoPiGo would work very well for teaching programming to younger students and possibly some older students. For older students the GoPiGo can also be used to begin teaching some basics of the Linux operating system with possibly implementing some minor cybersecurity solutions.

The GoPiGo kit is affordable for schools at only $249 for the base kit. Additional accessories can be purchased for larger schools that can afford it [11]. The GoPiGo is also very quick to setup out of the box. It can take additional time to download and install Raspbian for Robots if that is preferred, but for younger students it is more likely that the default operating system will be suitable.

All in all, the GoPiGo is recommended for use in primary and secondary schools to teach programming. It may be a challenge to teach cybersecurity, as the operating system is designed to be insecure. Thus, the GoPiGo is not recommended for use in primary and secondary schools to teach cybersecurity.

5 Mavic Air 2

5.1 Setup

5.1.1 Acquisition

The Mavic Air 2 is available on the DJI official website for individual purchase. Individually a Mavic Air 2 retails at $799 a unit, but at the time of writing this is on sale for $559 a unit. The base option comes with a drone, a remote controller, a battery, a battery charger, a power 3 pairs of low-noise propellers, 3 cables to connect a smartphone to the controller, a gimbal protector, and a controller charging cable [13].

Also available is the Mavic Air 2 Fly More Combo which retails at $988 a unit but is selling at $789 a unit at the time of writing. The upgraded option includes everything in the base option plus 3 more pairs of low-noise propellers, 2 additional batteries, a set of 3 ND Filters (ND 16, 64, 256), a battery charging hub that charges all 3 batteries at once, a battery to power bank adaptor, and a shoulder bag to hold everything [16]. For this research, 2 DJI Mavic Air 2 Fly More Combos were purchased at $799 a unit.

5.1.2 Construction

The Mavic Air 2 took about 30 minutes to construct the drone so that it was ready for configuration. During construction one of the propellers snapped very easily. This was not a major issue as the drone came with 8 extra propellers. Due to how easily the propeller snapped directly out of the box, however, we contacted the DJI support service to hopefully replace the broken propeller. The support service requires the customer to fill out a service request on the DJI website and then send your product back to them where they will conduct an assessment and repair before they ship it back to you [14]. This seemed unnecessary with all the extra propellers and the short time frame allotted for this research.

5.1.3 Configuration

Configuring the Mavic is simple enough. There are step by step instructions to download the DJI Fly mobile application and connect to your drone. To connect to the Mavic from the remote controller, a smartphone is required to be connected to the remote controller while running the DJI Fly application. The controller supports phones that use lightning, micro-USB, and USB type-C connections. To finish up configuration, install any firmware updates, which is done directly through the app, and everything is set to fly. Configuration was complete and the Mavic was ready to fly within 15 minutes after construction.

5.2 Flight

The Mavic Air 2 flies very easily with control done from the remote controller linked to the pilot's mobile phone running the DJI Fly application. There is an Advanced Pilot Assistance Systems (APAS) 3.0 obstacle detection system built in that gives warnings when flying too close to obstacles such as trees or buildings. The camera on the Mavic can capture video in 4k at 60 frames per second, and photos at 48 megapixels. The camera is automatically balanced using a built-in gimbal that includes 3-axis stabilization (tilt, roll, pan). The camera can be adjusted mid-flight from the controller. The Mavic comes with 3 batteries that, when fully charged, each allow for a maximum flight time of 34 minutes with no wind [15].

The Mavic can take off after a brief preflight check from the DJI Fly application, by holding a button displayed on the phone's screen. After takeoff a "home" waypoint is automatically marked for a simple, automatic drone return. The shoulder bag is incredibly convenient for storing and transporting all the necessary components for flight, including all 3 batteries.

There are 3 flight modes, cinematic, normal, and sport mode. The cinematic mode slows down the Mavic's speed to allow for better video and photo capturing abilities. The normal flight mode is the default that includes the use of the sensors and no restrictions on speed. The sport mode disables the obstacle warning sensors to allow for flying close to other obstacles without any noises or visuals being generated.

5.3 Discussion

5.3.1 Pros

The Mavic Air 2 is incredibly easy to construct and configure for a first-time flier. This removes any worries an institution might have regarding staff performing any construction, configuration, and implementation. Everything is simple enough to not put much strain on teaching staff with little technological knowledge or training to be able to implement the drone into their curriculum. The construction and configuration together take very little time to complete at about 30-45 minutes.

Of the 3 drones tested, the Mavic Air 2 is the most enjoyable to pilot. With an easy to control flight process and incredible camera. The Mavic can move at maximum horizontal flight speeds of 19 meters a second. There are also many different video capturing modes that make the process very simple. This is thanks to FocusTrack, 8k Hyperlapse support, and QuickShots. All modes are automatically included with the DJI Fly app [15].

5.3.2 Cons

The Mavic Air 2 lacks a free and easy-to-use programming application to program routes for a flight. The ability to create an app for an Apple iPhone 14, that was used in the testing, appears to be available, however it requires acquiring a Mac computer to create an application to run on the iPhone using XCode programming in either c or swift. The example starting app found in the DJI Developer mobile SDK documentation was very outdated and no longer worked with the current iOS, with many errors triggering from deprecated functions in both languages [12]. Due to a lack of time and resources, further exploration into this solution was unable to occur. Additional research could be done to develop an application that could be used to implement programming for the Mavic to make it suitable for use in primary and secondary schools as a tool to teach students programming while maintaining their attention.

Additionally, the Mavic Air 2 is not an entirely cheap purchase for schools with the base unit costing $799 a unit retail [13]. An institution could possibly get the funds to buy a handful of these drones with no need to worry about needing a large amount of time and resources to go towards constructing and configuring the drones. However, the institution would also need to purchase compatible smartphones to use for flight.

The propellers of the Mavic Air 2 seem to be very fragile and ample to breaking. Even with 8 additional propellors in the more expensive Fly More Combo, young students are known to break or damage equipment over the course of many uses. This could be avoided by restricting the actual flight and implementation to the staff. However, this can create a rift in a student's potential learning experience possible decreasing the maximum educational benefit they could get out of it.

Due to time and resource restrictions, not enough research has been done on potential cybersecurity implementations for the Mavic Air 2. A look into the wireless connectivity and a further understanding of the communication protocols used could lead to learning what kind of cyberattacks could be used against the drone. However, with the fragility of the propellors, much care should be taken when testing wireless attacks that could crash the drone.

There is a lot of focus on image and video capturing with marketing the Mavic [13]. This can open doors for data collection and image and video capture and storage attacks. Currently, however, more research needs to be done on the possible solutions and if any are deemed simple enough to be used to teach cybersecurity to students in primary and secondary schools.

5.3.3 Conclusion

With a proper programming application developed, or simple cybersecurity solutions to implement, the Mavic Air 2 could potentially be used as an educational tool in large institutions and as a rarely used treat to students for medium institutions to teach programming and cybersecurity. However, with the fragility of the propellers, lack of research in these two fields, and expensive price per unit, the Mavic Air 2 is not recommended for use in primary and secondary schools to teach students programming and cybersecurity.

6 GenCyber Summer Camp

GenCyber was a weeklong summer camp hosted by Michigan Technological University for fifty students in grades 8-12 in 2022. The goals of the camp include increasing interest and diversity in cybersecurity careers across the nation, helping students understand how to be proper digital citizens including proper online behavior, and to improve methods for teaching cybersecurity in K-12 curricula. The camp included different virtual pre-camp activities for the students and revolved around the theme: "Cybersecurity + AI" [8].

6.1 Pre-Camp Curriculum

The pre-camp activities included eight, one hour long, virtual activities: "GenCyber Kickstart Workshop", "Introduction to Computing Systems", "Introduction to Networking and the Internet", "Introduction to Programming and Algorithms", "Introduction to Data and Analysis", "Introduction to Impacts of Computing", Introduction to Cybersecurity", and "Introduction to AI". The sessions that analyze different methods to further the paper's mission statement are "Introduction to Programming and Algorithms", "Introduction to Impacts of Computing", "Introduction to Cybersecurity", and "Introduction to AI". Each section includes a twenty-minute slide show presentation followed by a thirty-minute hands-on activity. We describe these courses in more detail below [7].

6.1.1 Introduction to Programming and Algorithms

By the end of this module, the hope is for students to be able to explain programming and algorithms as a concept, explain what Python is, and write simple code using Python. The presentation goes over topics including data types, operators, logic statements, if statements, elif statements, and while loops. Following the presentation is an introductory lab where the students can begin coding in an online environment. The lab goes over everything talked about in the presentation, walking students through creating, manipulating, and printing variables. The course is followed up with review questions for the student to answer to test their knowledge on the topic [7].

6.1.2 Introduction to Impacts of Computing

By the end of this module, the hope is for students to be able to list the common types of modern computing technologies, describe their impact, and compare both the positive and negative impacts of them. The presentation goes over the types of impacts like intended, unintended, short-term, and long-term; the scale the impacts can have; positive and negative impacts; and connects everything to cyber-attacks to keep everything in theme. During the hands-on activity, students work in groups to list modern computing technologies, lists each technology's impacts, and categorizes each impact by type and scale [7].

6.1.3 Introduction to Cybersecurity

By the end of this module, the hope is for students to be able to explain cybersecurity as a concept and what ethical hackers are, list common best cybersecurity practices, and describe some common categories of cyber-attacks. The presentation goes over what cybersecurity is, what a hacker is, the CIAAN security model, common cyber-attacks, cybersecurity best practices, and different cybersecurity jobs. The hands-on lab walks them through a phishing quiz, haveibeenpwned.com [30], and building a secure password [7].

6.1.4 Introduction to AI (Pre-Camp Course)

By the end of this module, the hope is for students to be able to describe the concepts of artificial intelligence and big data, and to explain what bias data is in machine learning. The presentation goes over what AI is, the impacts of AI, how to train a system, bias data, what big data is, and big data's uses. The hands-on activity uses an ocean related AI simulator from code.org [31]. In the activity they train an AI to determine different types of fish. As the activity goes on, the student goes through stages that get more difficulty to understand the importance of putting an AI system through a lot of training. In the final part of the activity, the student trains the system to select each fish that matches a subjective adjective to open a discussion on biased data. After the activity, a discussion is had regarding the activity followed by a brief explanation to tie it back to the objectives they learned in the presentation [7].

6.2 Summer Camp Curriculum

The activities that took place during the week of the summer camp include many courses, a competition using GoPiGo, case studies, a Jeopardy game, a student project, a capture the flag competition, a poster session using posters made by the students, and an award ceremony all split into fifty-minute sections with some taking multiple sections. All sections take place over a five-day period. This paper focuses on the "Introduction to AI", "Introduction to Machine Learning I", "Introduction to Machine Learning II", "Neural Networks & Deep Learning", "Case Study: AI + Cybersecurity in DeepFake", and "Case Study: AI + Cybersecurity in Online Misinformation" sections [8].

6.2.1 Introduction to AI (Camp Course)

The "Introduction to AI" course took place on day one of the summer camp. This course aims to expand on the pre-camp "Introduction to AI" course that students participated in no sooner than two weeks prior. The fifty-minute section consisted of a twenty-minute slideshow presentation and a thirty-minute hands-on lab. The slideshow goes over the main parts of an AI system: datasets (inputs), predictions (outputs), and algorithms. Throughout the course, there are many examples throughout for students to partner up and try and figure out what a prediction and dataset might look like for different topics [8].

Towards the end of the lecture there is an activity where students try and write an algorithm for creating the best peanut butter and jelly sandwich, asking them to be specific. After the short activity a discussion is had on how specific an algorithm needs to be, with examples holding true to the peanut butter and jelly prompt. This exercise goes into a discussion on optimizing algorithms. If there is extra time remaining, students can run through the same code.org [31] activity from the pre-camp to review what they learned previously and connect it to what they learned today [8].

6.2.2 Introduction to Machine Learning I

Two courses for machine learning were created as separate sections. The first course was given on day two of the summer camp. The course consists of a short slideshow presentation, a demonstration of a trained machine learning model, and a longer activity. The presentation goes over supervised machine learning, specifically classification [8] [21].

The demonstration uses a model trained with Teachable Machine by Google [18] that determines if a given image is a dog or cat. The instructor uses test data to show how the model works and explain the model's confidence score [8].

After the demonstration, students partner up to go through an activity where they create a model and train it using two of three datasets. The available datasets are apples, oranges, or bananas. After training, students test their model with images from a test dataset and are asked what happens when the third fruit is shown to it. Models are trained and tested using public datasets from kaggle.com [32] [8].

6.2.3 Introduction to Machine Learning II

The second machine learning course takes place on day three of the camp. The course consists of a slideshow presentation and a hands-on activity for the students. The presentation goes over algorithmic bias in depth, showing a video and going through example models. During each example of a biased system, students are asked what is wrong with each model and how to fix them [8] [21].

After the presentation the course shifts to the hands-on activity where students work with a partner to create a biased model using Google's Teachable Machine [18]. Images to train and test their model are taken off Google Images [33]. Students are then asked to analyze the results of their biased model and instructed to remove any bias without removing the previously taught pictures. Afterwards, students explain what tactics they employed to attempt to fix their model [8].

6.2.4 Neural Networks & Deep Learning

The "Neural Networks & Deep Learning" course takes place on day four of the summer camp. The section consists of a slideshow presentation that include video examples and questions to open a discussion amongst students throughout. The presentation covers topics including components of neural networks, input/output weights, what deep learning is, and incorporating deep learning into neural networks [8].

There are four videos played throughout the presentation that show Google's DeepMind AI [27], OpenAI [3], a robot that teaches itself how to walk [29], and a generated conversation about becoming human between two AIs [26]. After each video, a discussion is had where students answered different questions to gain a better understanding of what they just watched [8].

6.2.5 Case Studies

There are two case studies given during a section during day four of the summer camp, "Case Study: AI + Cybersecurity in Online Misinformation" and "Case Study: AI + Cybersecurity in DeepFake". The section includes a presentation on both case studies as well as a worksheet for the Online Misinformation course [8].

In the first case study presentation, "Case Study: AI + Cybersecurity in Online Misinformation", students learn about disinformation campaigns following the RICHDATA framework from the Center for Security and Emerging Technology, and how AI is used in them. The framework describes the seven key stages of a disinformation campaign: Reconnaissance (R), Infrastructure (I), Content Creation and Hijacking (CH), Deployment (D), Amplification (A), Troll Patrol (T), and Actualization (R) [25]. For the case study, students look at the Pizzagate scandal [20] and fill out a worksheet to use the RICHDATA framework to analyze the scandal [8].

In the second case study presentation, "Case Study: AI + Cybersecurity in DeepFake", students learn what Deep Fakes are and what type of cyber attacks they can be used for. After learning the basics, students look at the case study from Red Asian Insurance, an e-commerce business that fell victim to a Deep Fake attack. The attacker used Deep Fake technology to mimic a supplier's voice and then called a manager impersonating the supplier asking for money. The manager sent the money believing the caller was the supplier as the Deep Faked voice sounded identical [6]. Students analyze the study and learn how to prevent Deep Fake attacks [8].

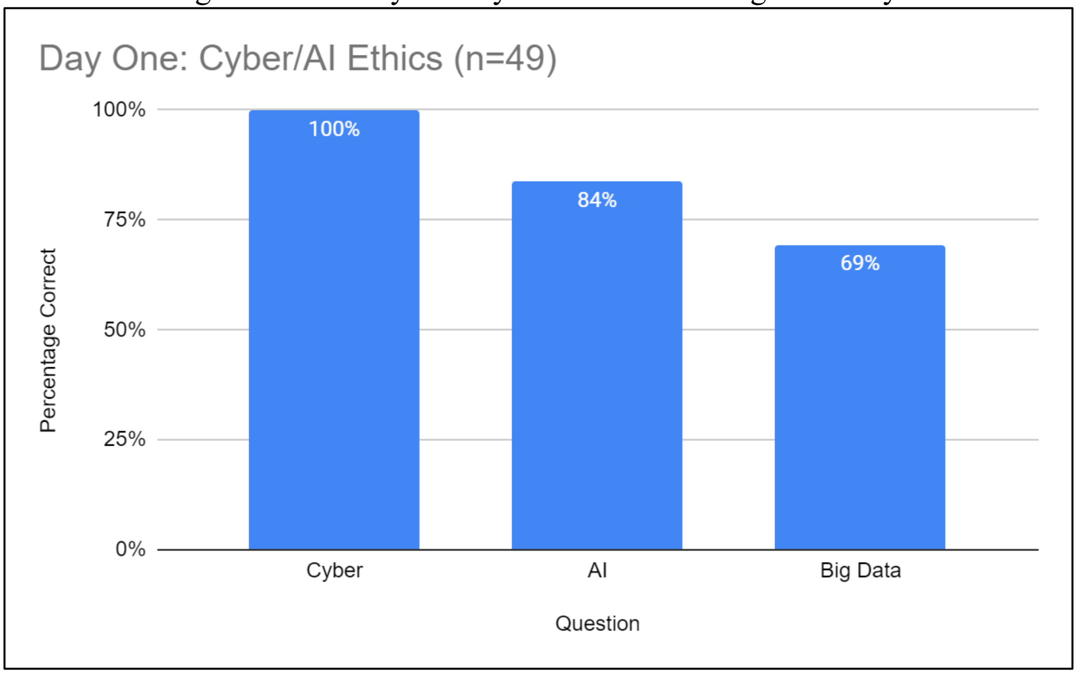
6.3 Results

Each day had certain learning objectives for the students. The objectives were based on the day's theme, and at the end of each day, students would fill out a Google Form that would test them on the objectives. Each form also included open response questions asking students what they found most and least useful or interesting as well as if they had any suggestions to improve the program.

6.3.1 Day One: Cyber/AI Ethics

Day one's theme was "Cyber/AI Ethics". At the end of the day, it was hoped that students would be able to describe what cybersecurity is and why it is important; explain what AI is; explain the 3 Vs of big data: volume, velocity, and variety; describe ethical issues and dilemmas; explain ethical concerns within the world of AI and cybersecurity; and demonstrate the ability to assemble and use a Raspberry Pi. The daily wrap-up form included the following questions: “What is cybersecurity?”, multiple choice; “What is artificial intelligence?”, multiple choice; “What are the three V’s of big data?”, choose all that apply; “What did you find the most useful/interesting from today’s program?”, open answer; “What (if anything) did you find not useful from today’s program?”, open answer, and “Do you have suggestions on how to improve today’s program?”, open answer.

Figure 6.1. GenCyber Day One Understanding Summary.



A breakdown of correct answers for the first three questions related to understanding the day’s topics are shown in Figure 6.1. All 49 students that responded to the day one daily wrap-up form showed an understanding of cybersecurity. 41 of the students correctly answered the questions connected to understanding AI. In terms of the 3 Vs of big data, 15 students answered incorrectly showing less of an understanding than the other major topics.

Table 6.1. GenCyber Day One Open Response Summary.

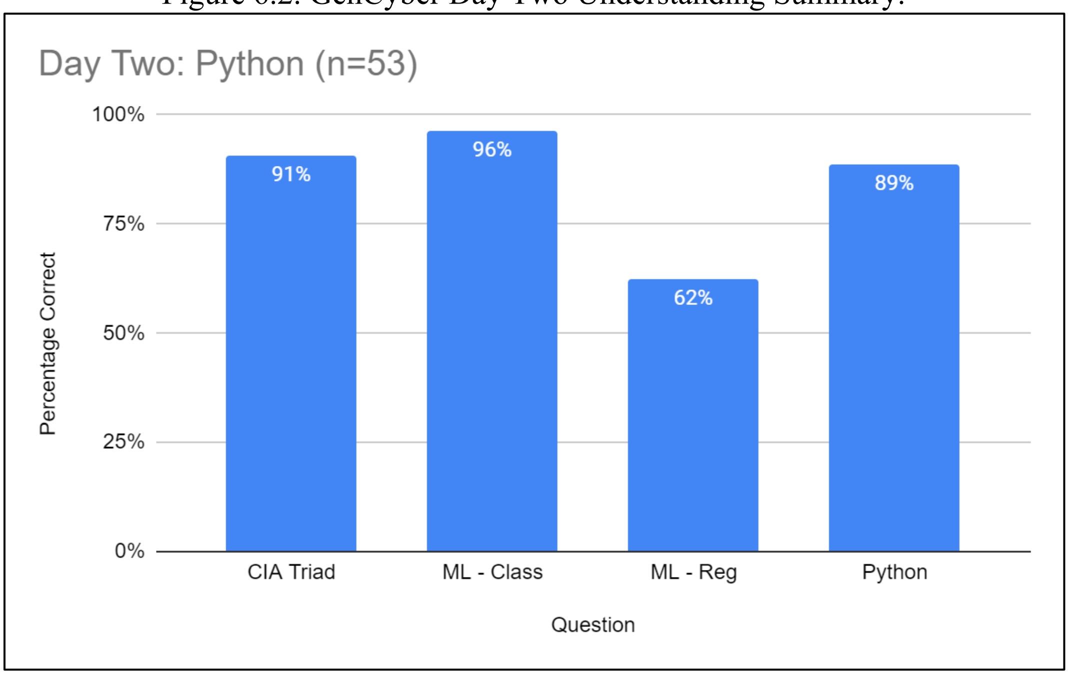
Most Useful/Interesting		**Not Useful**		**Suggestions**	
Topic	**Count**	**Topic**	**Count**	**Topic**	**Count**
Raspberry Pi	32	Nothing	33	None	29
Ethics	5	Ethics	4	Technical Problems	5
AI	5			More Hands-on Activities	3

A summary of some common themes from the open response questions are shown in Table 6.1. Note that only topics with at least 3 students mentioning are shown. Looking at the question asking students the most useful or interesting topic, 32 students specifically mentioned using the Raspberry Pi in some way, and 5 students each mentioned AI and ethics. 33 students replied that they did not find anything not useful, but 4 students felt the talks on ethics were not useful. For suggestions, 29 students had nothing to add, 5 students mentioned technical problems, and 3 wanted more hands-on activities. An interesting point is that 2 students suggested making the content harder or more complicated, while 1 student asked for the explanations to be slowed down a bit. This shows the range of knowledge that students might have acquired by themselves that still have the interest.

6.3.2 Day Two: Python

Day two's theme was "Python". At the end of the day, it was hoped that students would be able to describe the six GenCyber cybersecurity concepts; recognize the CIA Triad and explain each section; state the concept of machine learning; explain what Python is and why it is popular today; explain standard input and output in Python; and demonstrate the ability to write and execute a basic Python program. The daily wrap-up form included the following questions: "What does the CIA Triad stand for?", multiple choice; "What are the two types of machine learning?", choose all that apply; "How would you define a function in Python?", multiple choice; and the same three open response questions as the previous day.

Figure 6.2. GenCyber Day Two Understanding Summary.



A breakdown of correct answers for the first three questions related to understanding the day's topics are shown in Figure 6.2. 48 of the 53 students that responded answered the

CIA Triad question correctly. For the machine learning question, 51 students selected classification while only 33 selected regression. This could be because the students worked on a classification machine learning model, so they recognize it more. When defining a function in Python, 47 students answered correctly.

Table 6.2. GenCyber Day Two Open Response Summary.

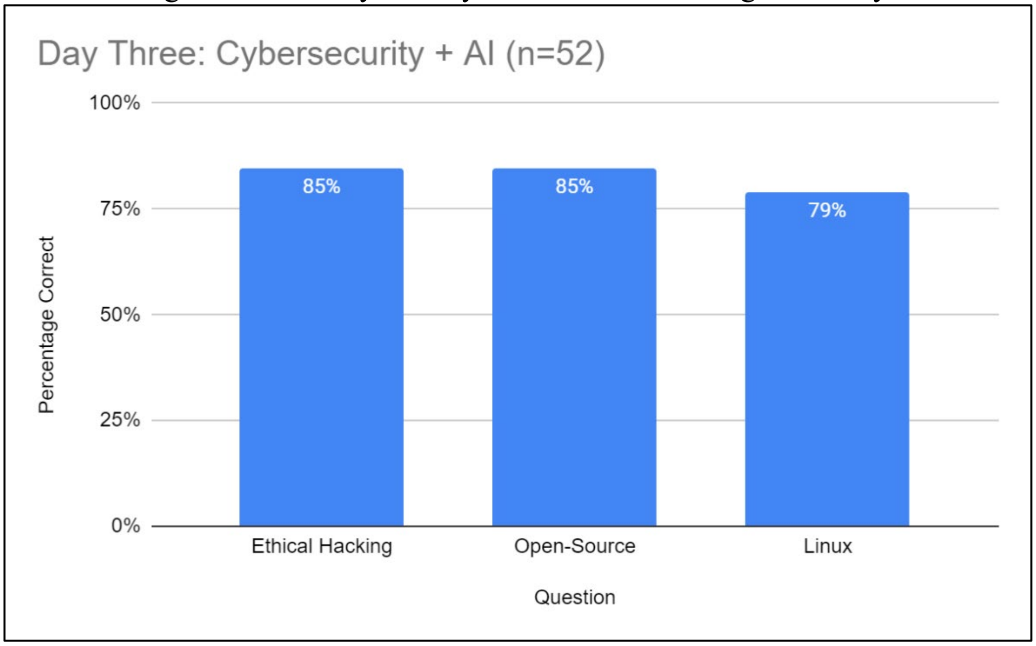
Most Useful/Interesting		Not Useful		Suggestions	
Topic	**Count**	**Topic**	**Count**	**Topic**	**Count**
GoPiGo	26	Nothing	32	None	24
Python	18	GoPiGo	11	GoPiGo	10
CIA Triad	3	Python	4	Not Enough Time	7

A summary of some common themes from the open response questions are shown in Table 6.2. Note that only topics with at least 3 students mentioning are shown. With regards to the most useful/interesting topic of the day, 26 students said using a GoPiGo and 18 students said Python. For not useful topics, 32 students said nothing was not useful. 11 students put something related to the GoPiGo including construction issues, connectivity issues, and their general usage. 4 students felt Python was not useful as some felt it was too simple while 1 said he was struggling to grasp the topics in any meaningful way. For suggestions, 24 students had none. Regarding the GoPiGo, 10 students had issues, although 4 were connection-based issues from the robots all having the same default name out of the box. Other issues included dissatisfaction of its operation and construction instructions. 7 students suggested adding more time, 1 student asked to go slower during programming instructions, and 1 student asked to move faster.

6.3.3 Day Three: Cybersecurity + AI

Day three's theme was "Cybersecurity + AI". At the end of the day, it was hoped that students would be able to describe and provide real world examples of algorithmic bias; define and explain the purpose of ethical hacking; describe typical steps that take place during a cyberattack; explain what Linux is; explain open-source; explain what Kali is and its features; demonstrate the ability to use basic Linux commands; Explain the Linux file permissions and how they are set; explain the basic components that make up a computer; and demonstrate the ability to assemble and disassemble a computer. The daily wrap-up form included the following questions: "What is ethical hacking?", multiple choice; "What does it mean for a program or operating system to be 'open source'?", multiple choice; "How would you create a new text file in Linux?", multiple choice; and the three open response questions as before.

Figure 6.3. GenCyber Day Three Understanding Summary.



A breakdown of correct answers for the first three questions related to understanding the day's topics are shown in Figure 6.3. 44 of the 52 students answered the ethical hacking question correctly. 44 students got the open-source question correct as well. For the Linux question, 41 students got it correct. As the camp goes on, it seems as though the amount of correctly answered questions slightly drops as we go.

Table 6.3. GenCyber Day Three Open Response Summary.

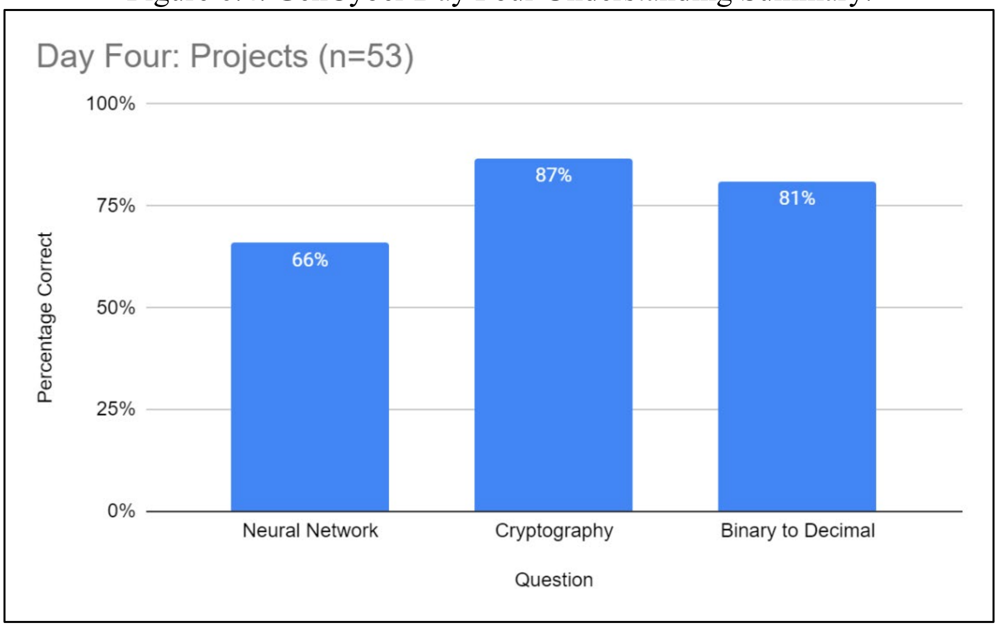
Most Useful/Interesting		**Not Useful**		**Suggestions**	
Topic	**Count**	**Topic**	**Count**	**Topic**	**Count**
Computer Assembly/ Disassembly	23	Nothing	42	None	39
Jeopardy	12	Computer Hardware	3	Jeopardy Bias	3
Linux	11	Linux	3		
Ethical Hacking	3				

A summary of some common themes from the open response questions are shown in Table 6.3. Note that only topics with at least 3 students mentioning are shown. Day three was the day of the Jeopardy review game and this was seen in the long response questions. 12 of the 52 students put Jeopardy as the most interesting/useful part of today. The computer assembly and disassembly section was the most interesting/useful for 23 students. Linux was also prominent being the choice of 11 students. 42 students felt that nothing was not useful for this day. 3 students each felt either the computer hardware or basic Linux commands were not useful. 39 students had no suggestions today, and there were not any other semi-popular suggestions, besides requesting less bias in selecting the winner for the Jeopardy review game.

6.3.4 Day Four: Projects

Day four's theme was "Projects". At the end of the day, it was hoped that students would be able to define the goal of neural networks, describe the four main components of neural networks, explain deep learning algorithms, define cryptography, explain Caesar Cipher and how it can be broken, understand how to convert binary to decimal, and explain neural network applications like Deep Fakes. The daily wrap-up form included the following questions: "Choose the option that is NOT one of the four main components of neural networks:", multiple choice; "What is cryptography?", multiple choice; "What is the binary number 11110111 in decimal?", multiple choice; and the same three open response questions as before.

Figure 6.4. GenCyber Day Four Understanding Summary.



A breakdown of correct answers for the first three questions related to understanding the day's topics are shown in Figure 6.4. Only 35 of the 53 responding students got the neural network question correct, showing a third of students lack an understanding of neural networks. 46 students correctly identified the definition of cryptography. For the binary to decimal conversion question, 43 students got the correct answer.

Table 6.4. GenCyber Day Four Open Response Summary.

Most Useful/Interesting		Not Useful		Suggestions	
Topic	**Count**	**Topic**	**Count**	**Topic**	**Count**
Cryptography	25	Nothing	46	None	42
Student Project	10	Cryptography	3		
Neural Networks/ Deep Learning	7				
Deep Fakes	6				
Cybersecurity Scholarships	3				
Cybersecurity Careers	3				

A summary of some common themes from the open response questions are shown in Table 6.2. Note that only topics with at least 3 students mentioning are shown. 25 of 53 students found learning about cryptography useful/interesting. 10 students found use in the student project which includes group research, poster making, and a presentation. 7 students found the neural network and deep learning section useful/interesting. 6 students enjoyed the Deep Fake case study. 46 students did not find anything not useful today. Cryptography was deemed the largest non-useful topic with 3 students mentioning it. 42 students had no suggestions, with no other suggestion reaching a minor consensus.

7 Conclusions

7.1 Final Discussion

Table 7.1. Drone comparisons

Drone	Cost	Ease of Setup	Ease of Operation	Programmable	Cyber Attacks	Cyber Solutions
Pixhawk Quadcopter	$899	No	No	Yes	Yes	Yes
GoPiGo	$249	Yes	Yes	Yes	Yes	No
Mavic Air 2	$799	Yes	Yes	No	No	No

Every evaluation point of each drone is summarized in Table 7.1. After looking at the three different types of drones, the GoPiGo is the only one that can be recommended for use in primary and secondary school to teach programming. This is due to the GoPiGo's low cost; simple construction, configuration, and implementation; and ability to scale as students get older through purchasing new projects or implementing Google's Cloud Vision API for advanced programming projects.

Additionally, the GoPiGo's use was seen during the GenCyber summer camp. The robot was used as the medium for students to learn an introduction to programming and was used in a race between groups. It was well received by students with 26 of 53 respondents to the day two wrap-up form said the GoPiGo was the most useful or interesting topic of the day.

All three of the drones looked at, the Pixhawk Quadcopter, GoPiGo, and Mavic Air 2 failed to meet enough of the specifications to be recommended for use in primary or secondary school to teach cybersecurity. This is due to the Pixhawk Quadcopter's price and complex construction, configuration, and implementation; the GoPiGo's insecurely designed operating system that makes it near impossible to try and implement any solutions; and the Mavic Air 2's price and part fragility.

In terms of the ability to teach cybersecurity and programming to secondary school students, it has been seen that the GenCyber summer camp has had some success with teaching basic programming and cybersecurity. As the topics got more advanced, like AI, we saw a general drop in students getting the correct answer on the wrap-up quizzes. However, it was observed that more than half of the students can show a general understanding of all the topics. The mediums that appeared to work best are incorporating unique ones that held students' attention. Mediums that accomplished this are the GoPiGo, including hands-on activities in each section, and incorporating fun games such as the Jeopardy review or GoPiGo race.

7.2 Future Research

There were multiple topics that were unable to be researched thoroughly due to time restraints. Going forward, research could be done into the Mavic Air 2's wireless connectivity to discover attacks against its wireless connection as well as solutions to any found attacks. Due to the Mavic's focus on its photo and video capture, research could be done to look for attacks targeting its camera and photo/video data communication and storage as well as solutions to any found attacks.

An application could be developed for the Mavic Air 2 to allow for programming it through Apple or Android applications. There is documentation available, but the sample codes were out of date and an app could not be created from scratch due to time restraints.

Additional research could be done to reviewing, refining, or implementing curriculum from camps such as GenCyber to see how they might transfer to a general classroom setting. It could be beneficial to look at the sections from GenCyber to see if they could be incorporated into current classes in some way. I would be interesting to see how this information would be received when given to the general student populous, not just students who willingly sign up for a camp due to known or possible interests.

While wrapping up this research, a drone with a possibility of being useful for either teaching programming or cybersecurity in primary and secondary school was discovered. The Tello EDU is a small programmable drone designed for education. The Tello is developed by DJI and is very cheap at only $129 a unit. The Tello is a promising solution that was missed in initial research, that could benefit from further research [22].

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