Should the US Military Use Drones in Wartime?

Ariel Coff

SLA-MS

Abstract:

The Science, Engineering, and Operation of Drones seminar inspired the following curriculum. This *Teachers Institute of Philadelphia* unit will help 7th-grade students to practice the skills of argumentative writing, scientific modeling, and reasoning with cross-cutting concepts in the context of the observable phenomena of a drone. Students will formulate questions about the ethics of a drone's recreational, commercial, and military applications. They will learn about how electromagnetism, mass-related forces (gravity, drag, lift, and propulsion), and fluidic motion interact to result in a flight. They will design and test their own gliders, and manually fly, write codes, and collaboratively run codes with drones. They will find that these unmanned aircraft have unique uses, and also come with a unique set of problems. Students will understand that UAVs, like many forms of technology, must be regulated to mitigate potential harm.

Keywords:

Investigation, experimental design, fields of force, electromagnetism, forces and motion, Newton's Laws, model, energy waves, drones, technology, coding, robotics, fluid dynamics, research, scientific argument, ethics, debate

Unit Content

During our seminar, we had a conversation about the future. Are young people in the US actually being prepared for jobs with drones and robotics? Can students persevere through building basic knowledge in order to critically think and invent? According to the *Trends in International Mathematics and Science Study*, a multinational assessment, "In the eighth-grade tests, seven out of 37 countries had statistically higher average math scores than the U.S., and seven had higher science scores."[1] Something needs to change if we are going to compete in the innovation and technology sectors. Teachers must be proactive. Over a fall semester, we explored a wealth of material while gaining hands-on experience in coding for and flying drones. All four of *NGSS' Physical Science Disciplinary Core Arrangements*,[2] programming, certification guidelines, and various stakeholder perspectives are featured in the course content. The following text provides prerequisite knowledge for middle school teachers who wish to use this unit. Sections explain the molecular makeup of some drone components, relationships between fluidic density and motion, Newtonian mechanics in context, sensors and functions, energy transfer and conversion, electromagnetic (EM) waves (frequencies, transmission, and reflections), coding terms, FAA

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[1] Desilver, 2017
[2] NGSS, n.d.

regulations, and controversial topics. Discrete lesson guidance is embedded in a detailed Classroom Activities section.

Matter and its Interactions are well-demonstrated in the physical properties of the types of elements that make a drone's parts. It has a lightweight yet rigid frame (carbon fiber), so it has impressive tensile strength but is not particularly impact-resistant.[3] Drone motor brushes are made of graphite or copper, materials with a low lifespan and high maintenance. Drones with brushless motors are more energy-efficient because they generate less friction.[4] Hobby drones' motor wires are often fragile, and because of this they can bend or break easily in a fall. Lithium polymer batteries are very energy dense, and are most popular, but there are also lithium ion and nickel hydride battery options. Overcharging or mishandling these can lead to a dreadful fire; it's impossible to put out without smothering in a bucket of sand, and for this reason they should only be disposed of properly. Charge and discharge processes are helpful to understand, and well-described by the *US Department of Energy*: "While the battery is discharging and providing an electric current, the anode releases lithium ions to the cathode, generating a flow of electrons from one side to the other. When plugging in the device, the opposite happens: Lithium ions are released by the cathode and received by the anode."[5] Density and pressure of matter are important features of an integrated flight model.[6] Bernoulli's principle for lift is what pushes the drone upwards; highly pressurized air is able to flow under the flat side of a plane's wing, while the curved shape of the top side of a wing forces air over it more quickly, causing low pressure there. When air is denser below than above, lift is the result.

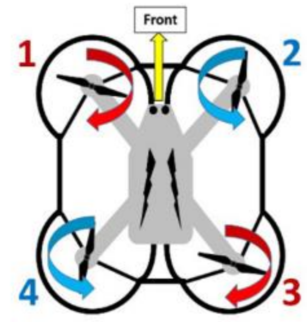

Figure 8. Propellers spin in different directions to cancel out the torque.

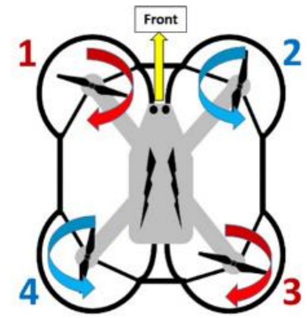

Figure 10. Top view of a quadcopter showing propellers rotating clock-wise and counterclockwise.

Motion and Stability: Forces and Interactions are the aspects of this course that are observed with the human eye. The unbalanced forces that control the directional movement of a drone are due to high acceleration, so there is an unbalanced torque on whichever blades experience this, and thus change in motion.[7] Each of the counter-angled propellers rotate in the same direction of the one diagonal from them, for balance (see the diagrams from *STEM LEARNING: Advanced Air Mobility: The Science Behind Quadcopters Reader—Student Guide*).[8] The varying speed of these diagonal groups determines the drone's flight paths; unbalanced force on the horizontal axis gives thrust.[9] More than four propeller blades results in more lift, but these tax the motor and therefore the battery proportionately. The longer the propellers, the more mass they can lift. The shorter the propellers, the more agility the drone has. Newton's 3rd Law (of

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[3] Mirdehghan, 2021
[4] Liang, 2019
[5] Minos, 2023
[6] Hall, 2022
[7] Hall, 2021
[8] NASA, n.d.
[9] Corrigan, 2020

every action having an equal and opposite reaction) necessitates at least 2 propellers, one on top and a tail rotor of perpendicular force that counters torque; with only one propeller, kickback would cause the body of the drone to spin in the opposite direction. Newton's 2nd Law (F=ma) proves that the greater the propeller speed is, the greater the lift force will be. Students should also consider these complexities: air resistance causes drag, and as a drone flies, it displaces an equal mass of air around it. The drone uses an initial measurement unit (3-axis gyroscope [measuring directional movement] and 3-axis accelerometer [measuring acceleration], and also magnetometer [which measures the strength and direction of magnetic fields]) to orient itself. Gyroscopes measure angular velocity by measuring the coriolis force (a force in one axis, resulting from a rotational force on another axis and a thrusting force on another axis). They do this by sensing microscopic changes in fixed-based plates' movement and adding up those vector quantities to find a net force.[10] Accelerometers are made of electrically charged plates and counter-plates, and a capacitor (power storage and supply). The plates squeeze together more or less when motion changes, thus creating a greater or smaller force. Since the mass of the plates remains constant, the change in force is directly due to acceleration, which can then be calculated.[11] Three types of magnetometers can be used in drones. Hall effect magnetometers work by sending an electrical current through a semiconductor, assessing any distortions to the current, and quantifying voltage differences to find the strength and direction of magnetic fields. Magneto-resistance magnetometers measure proportional changes in the electron spins of atoms in ferromagnets to find their resistance to magnetic fields around them. Fluxgate magnetometers run an alternating current through one coil, sense fluctuating currents in another coil, and attribute differences directly to background magnetic fields.[12] A barometer can measure different atmospheric pressures in flight in order to sense altitude.

Energy is best demonstrated in the conversions that occur. Students may show this in their final model of drone parts and functions. Chemical energy in a ba e this history of science inspiration from *Energy Minute*: "Scientists such as Nicolas Léonard Sadi Carnot, Rudolf Clausius, and Lord Kelvin formulated the laws of thermodynamics, which provided a deeper understanding of energy conversions and the principles governing them. James Prescott Joule conducted experiments that established the relationship between mechanical work and heat, leading to the concept of the conservation of energy."[13] Students may think that heat and high temperature are synonymous; this distinction should be clarified. My suggestion would be that students form groups and do research presentations about these scientists' work and discoveries, including models that explain how the laws of thermodynamics and conservation of energy play out in the real world, as well as on a molecular scale.

Waves and their Applications in Technologies for Energy Transfer are core components of drone-controller pairing, the information they communicate to other systems, and methods for information-gathering in drones. A drone frame houses a flight controller with a microcontroller, which communicates to the remote controller in a 2.4 GHz frequency in short distances, or a 900 Mhz band in long distances. Other, proprietary frequencies are used by the military. This variety of communication channels allows for multiple signals to coexist without interfering with one

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[10] Practical Ninjas, 2017
[11] Omega, 2023
[12] Prabhu, 2021
[13] Foyer, 2023

another or gasses in the atmosphere.[14] These waves are of particular interest because unencrypted binary code between controller and drone can be intercepted, which would allow a bad actor to hijack a device. Additionally, jamming and interference can interrupt signals, and malware can infect software and gain unauthorized access to information.[15] The drone itself uses waves to generate various sensor inputs that are computed a thousand times per second. Drones can find the positions of the objects around them by projecting infrared light from a front sensor, which uses the amount of time it takes for that light to reflect back to calculate distance. These related positions are input into an AI coordinate plane in the onboard controller.[16] An "optical flow" sensor helps a drone to orient itself by sensing changes in motion; in a CoDrone EDU drone, this sensor is pointed downwards. Since flying over uneven surfaces makes this type of 3-D orientation more complex, an internal measurement unit and sensor fusion algorithms are crucial in estimating position.[17] Colors of objects are assessed by the reflected lights' wavelengths and using the process of omission to see which have been absorbed.

Programming should be thought of as a language, with its own syntax rules. Code can be easily read by *compilers*, which are programs that convert it from one language to assembly/machine language, for example, from Python to binary. *Interpreters* translate the code into actions at runtime.[18] Code should be clear and consistent, lending itself to efficient updates or changes where necessary. *Statements* are codes for actions to be performed. *Variables* are inputs to the program that can change the outcome of actions. *Operators* give compilers directions about numerical operations, comparisons, or specific decision-making, with words like *and*, *or*, and *not*. *Conditionals* are if-then statements that an interpreter can use. *Functions* are chunks of code that define certain repeated tasks. *Loops* are actions that repeat until a predetermined condition is met. Algorithms are programmed into a drone; they are sequential, conditional, and iterative processing codes. Students do not need to know all of this vocabulary to operate drones, though many of these terms are intuitive.

Certification is necessary for everything except recreational flying of drones. Some basic safety musts are that every drone over 250 grams must be registered with the FAA, yield to aircraft, be labeled, and be in the operator's line of sight. Safety don'ts include flying more than 400 feet above the ground (or low above people, events, or moving vehicles), and night flies. The *B4UFLY App* is a worthwhile download; it gives warnings about nearby obstacles via interactive maps.[19] The Remote Pilot Certificate with Small UAS Rating can be issued by the FAA for anyone who submits an application, has English fluency, is physically and mentally fit for drone control, and passes an aeronautical exam. This test's content includes airspace designations, weather's impact on flight, load's impact on flight, navigation and decision-making, radio contact guidelines, and airport procedures, among other content. Anyone who passes is required to take a refresher course every 2 years.[20] These regulations are sure to develop along with future drone technology.

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[14] Cadence Design Systems, 2023
[15] Abidi, 2023
[16] Nguyen et al., 2022
[17] MathWorks, 2023
[18] Mitchell, 2022
[19] Federal Aviation Administration, 2022
[20] Federal Aviation Administration, 2023

Drones are not just simple objects; they are bathed in controversy. Conflict is anticipated and welcomed in our arguments from evidence at the end of the unit. To structure this research, student-friendly sources for inquiry are embedded in the penultimate lesson, and these prescient topics are summarized here. The anchoring phenomenon of combat and spy drones can be explored first. Military drones are being redeployed by local police forces, ostensibly keeping an eye on protestors and possibly infringing on first amendment rights. (Guariglia, 2021). Local law enforcement agencies are already testing Drone as First Responder programs, in attempts to use situational awareness to reduce response time, de-escalate situations, and clear structures that are dangerous for a human to enter. (BRINC Drones, 2023). The CIA uses drones' capabilities to prepare for smooth operations like Neptune Spear (the capture of Osama Bin Laden), when national security objectives must be carried out without a hitch. (Morton, 2023). The US military is now funding a "university" to prepare soldiers for countering unmanned aerial surveillance. (Park, 2023). Distinguishing civilians from combatants in wartime continues to elude our military, and even though drone strikes are supposed to be "limited to areas of active hostility," the majority of targeted locations are unknown. (Drone Wars, n.d.). Since US drones can operate in countries without requiring physical military bases, we use them in places we have never declared war upon, such as Somalia, Pakistan, and Yemen. (The Bureau of Investigative Journalism, n.d.). *Predator, Reaper,* and *Global Hawk* drone pilots show the same "clinical distress" as front-line soldiers (including depression and anxiety), can develop post-traumatic stress disorder, and have similar responses during combat (for example, elevated heart rate and adrenaline). (Chow, 2013). Students may ask themselves about the ethics of control and remoteness, and whether distance actually removes responsibility.

There are quite a few issues with drones and human rights: to our own spaces, faces, belongings, and pursuit of happiness. Nature can't speak for itself, but its advocates can. Privately-used drones may trespass on private companies and property, and even perform wireless attacks, and it is against the law to shoot them down. (Kohnke, 2023). The rights of federal Indian reservations and territories are better, though somewhat limited: "Only the FAA can restrict airspace…, (it) recognizes that drone safety is a partnership with local, state, tribal, and territorial government entities who have rights to regulate where drones are allowed to take off and land." (Federal Aviation Administration, 2023). Biased facial recognition software has difficulty in distinguishing the gender of everyone but white people, so is it legitimate for identification purposes? (Buolamwini, 2018). Smugglers crossing the US-Mexico border have been using drones to find paths of least resistance. (US Department of Homeland Security, 2023). There is still a lack of insurance for drone technology or the damage it can do. (Michigan Technology Law Review, 2019). Drone data storage can be expensive, since security and reliability come with a cost. (Frackiewicz, 2023). US National Parks have banned drones, because fliers have harassed animals and otherwise disturbed ecosystems, but other natural areas are without protection. (Santora, 2021). Students could ask whether our government is more concerned with protecting its own belongings than it is with protecting privacy, personal property, and living things.

The context of artificial intelligence and robotics is rounded out with some benefits: drones can also be used to save people and the environment. Medication and hospital-grade meal deliveries might soon be quicker, easier, and more eco-friendly, increasing accessibility for those who choose at-home care. (Robins, 2023). Search-and-rescue drone swarms can see through obstacles, cover ground more quickly, strategize, and communicate findings seamlessly, to save lives sooner. (Virginia Tech Engineer, 2021). Emission-monitoring drones can collect data from sea vehicle exhaust plumes, and assist in making a case for pollution accountability. (Nordic Unmanned, 2012). Industrial drones can do "aerial surveys and mapping to collect geospatial data, monitor and inspect infrastructure such as buildings, bridges, and pipelines, perform crop monitoring and precision agriculture in the farming industry, conduct search and rescue operations, and even transport goods in certain scenarios." (Haiston, 2023). Knowing and understanding the information a drone has collected can help to judge risks, make predictions, prevent accidents, ensure efficient operations, and decrease costs (Netto, 2023). Lastly, while drones might replace humans in some jobs, they will also create jobs. (ABC News, 2014). Just like our students, scientists and engineers should consider the effects of drones on the environment and society, and they should critically think about the credibility of any information they use to do so.

Teaching Strategies

This unit is built around a Socio-Scientific Issue (SSI). Like other SSIs, the military applications of unmanned aerial vehicles "involve the deliberate use of scientific topics that require students to engage in dialogue, discussion and debate. They are usually controversial in nature but have the added element of requiring a degree of moral reasoning or the evaluation of ethical concerns in the process of arriving at decisions regarding possible resolution of those issues." (Zeidler and Nicols, 2009).[21] Sense-making is more meaningful for students when it is relevant to their lives and times; in this case, the mechanisms behind cutting-edge technology of remote aircraft are juxtaposed with the mechanisms of the systems in which they function. Students are motivated to figure things out. Teachers can learn from their students, and build relationships via science talk. Here is how it works.

First, an anchoring phenomenon is introduced (in this case, a bomber drone), which the unit will build upon and return to, and is puzzling to students. Then, a debatable question is posed: Should the US military use combat drones? Students place a written, reasoned opinion on an opinion line in response to that question, and discuss their ideas. Then, they construct initial models in an attempt to explain how a drone works. We then collaborate to create an initial consensus model about drone functions for our classroom. After that, we study some background information on types of drones, and notice their similarities and differences. We place the questions we generated so far on a Driving Question Board. These questions are individualized at first, but grouped later, and the procedure requires students to listen to one another, think about each other's ideas, and share talk time.

Through research and student-designed investigations of molecular motion, contact and non-contact forces, and electromagnetic communication signals, we explore some fundamental topics that help us to understand the drone phenomenon better, and hopefully answer some of our questions. We navigate into assessing which questions we've answered, as well as figuring out what we still don't know. Our summative project is to make models of specific aspects of a remotely-controlled drone and its mechanics, code for and fly a drone, create and publish a final integrated model, argue a perspective from evidence, evaluate the resources we've used, and submit a completed progress tracker of our learning. Finally, we close the unit by revisiting our

[21] Zeidler & Nichols, 2009

Driving Questions and engaging in a debate to discuss our now-informed opinions about whether or not the US military should use combat drones.

The unit is project-based, which “involves students designing, developing, and constructing hands-on solutions to a problem. The educational value of project-based learning is that it aims to build students’ creative capacity to work through difficult or ill-structured problems, commonly in small teams.” (BU Center for Teaching and Learning).[22] In order to evaluate the efficacy of the units’ tasks, they were examined in 8 domains: phenomenon-driven, scenario-based, rote-resistant, reasoning-centered, rooted in disciplinary core ideas, science and engineering-practice-laced, coherent for students, and able to separately assess each of the three NGSS dimensions.[23] When students developed EM wave behavior models, they learned about and addressed the paths of light, as well as the structures and functions of materials involved. When they planned and carried out an investigation into how a battery moves a propeller, they understood that changing an EM force at a distance could affect how a motor runs. When they used simulations to figure out the forces of flight, and tested their understanding in controlled conditions, they were able to contextualize stability and change.

Participation techniques include think-pair-share, group talk, and whole class debate. Various grouping strategies (single, pairs, small groups, and drill lines) are employed to add interest to student collaboration while preserving some individualized focus time. The work is intentionally flexible: students speak, listen, read, write, draw, collect and communicate data, and present in order to authentically explore the content in ways that are accessible to them. In this way, those with special education or English language learner statuses can practice skills in tandem with content-specific vocabulary in the real world. The methodologies are inquiry-based; this unit “validates ‘habits of mind’ that characterize a life-long learner: It teaches students to pose difficult questions and fosters the desire and skills to acquire knowledge about the world. (They are) given opportunities to take ownership of their own learning, a skill necessary for one to succeed in college and in most professional settings.” (Sweetland & Towns, 2008).[24] Students have choice how they problematize, plan, build, design, obtain, and contextualize information, just as professional scientists would.

Classroom Activities

STAGE 1: Desired Results	
Established Goals	Transfer

[22] BU Center for Teaching and Learning. n.d.
[23] Achieve, n.d.
[24] Sweetland & Towns, 2008

Standards: NGSS: **MS-PS4-2.** **MS-PS2-5.** **MS-PS2-2.** Common Core: **ELA CC.1.4.7.W.** **ELA CC.1.4.7.C.**	Students will be able to independently use their learning to: ● Create a model of energy's path from controller to processor in a drone. ● Design an experiment to explain how a battery that isn't in contact with a propeller can cause it to move. ● Design an investigation to learn which unbalanced forces cause flight. After obtaining and evaluating this information, communicate it in the form of a diagram. ● Make and test a paper airplane. ● Fly a drone with both a controller and code. ● Construct an argument from evidence about which applications drones are/aren't appropriate for, and why. ● Evaluate source materials using a credibility rubric.

STAGE 2: Evidence	
Evaluative Criteria	Assessment Evidence

Performance is judged in terms of… A rubric (see appendix) will be used to evaluate the transfer tasks by standards.	**Transfer Task(s)** (What assessment(s) will provide understanding and meet other Stage 1 goals?) Students will: Create a model that shows how waves were reflected, transmitted, and absorbed through various materials, from the controller to the drone, in order to tell it to move. Design an investigation of the relationship between electricity and magnetism to explain how a battery that isn't in contact with a propeller can cause it to move. Conduct an investigation that answers the question *How do the mass and parts of the plane affect the sum of forces that cause it to fly or fall?* Design a glider with optimum lift or thrust. Independently write a code, and work in groups to help each other fly the drones manually and with codes. Create a final model that integrates wave properties and behaviors, electromagnetism, unbalanced forces, and drone mechanics to answer the question *How do drones fly?* Engage in debate on the unit's titular question with solid evidence from credible sources. **Other Evidence** Initial and final models, google forms, science notebook check (for comprehensive notes and graphic organizers), discussion participation (evidence of understanding and misconceptions), and group work.
Where is this leading to?	A unit on artificial intelligence follows this one; students will evaluate the efficacy of analog and digital signals, and continue to develop coding skills in order to carry out tasks set for the CodroneEDU. We'll focus on the socio-scientific issue of whether AI creations should replace their human-made counterparts.

STAGE 3: Learning Plan	
Day (20 hours total)	Activities and Notes

<table>
<tr>
<td>Lesson 1
1 hour</td>
<td>Watch CNN Rides With Ukranian Drone Unit . Then introduce the idea of the opinion line. Here’s the question: Should the US military use combat drones? Have students write their name and the issues they are most concerned about on a sticky note and place it somewhere from “definitely” to “never.” Then ask students along the continuum to explain their answers and reasoning. Remind students that there is no “right” answer here, but they should make a choice with conviction.
Discuss and share: What do you all know about drones? How do we use coded robots in our everyday life? Now, let’s look at some related phenomena. Set up a Notice-Wonder chart in your science notebooks. Watch Teaching drone swarms to assist in search and rescue efforts, and Gathering both drone and ‘human’ intelligence. Share out: What are some things that caught your attention about these drone applications? What do you wonder about them? Students may comment on human and military impacts, and drones as life-savers. Then pose the questions: “How do drones work? Why have drones become important in modern warfare or civilian life? What are the costs and benefits of using them in the military?” Explain to students that we will be exploring this content deeply in the upcoming unit. We’ll start with doing an initial model about parts and their interactions. Try to explain energy’s role!
Individually, you will do individual models to address these questions: How do drones work? How does a signal get from a controller to the drone? These models are made to show how a process could work, and do not yet need to be correct. Then, we will share our ideas to create a class consensus model. Begin a Progress Tracker in the back of your science notebook, and add an entry at the close of class. You’ll need 3 columns, and you will add to these when prompted to do so throughout the unit.
<table>
<tr><td>What we were trying to figure out</td><td>What we did</td><td>What we noticed and learned (and how it relates to drone uses and functions)</td></tr>
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Lesson 2 1 hour	We started to talk about drones. You did your initial models to try to explain how they work, and how they receive commands. But how could we find out more about their structures and functions? *Students will likely suggest to research or look at real drones in person.* Good ideas. Each table will look at a drone up close. See which parts you can name, and try to illustrate the parts of a drone WITHOUT looking anything up. What are you seeing that you can't explain? Discuss in your groups, and share. *Write student ideas on the board, highlighting those that align best with the day's investigation*. Then, access Robolink: Getting to Know Your Drone. Using this resource, label and or draw any parts that weren't in your first diagram. What was new and/or interesting? Discuss as a class. Add an entry to the Progress Tracker. So now that we have all of this to think about, which questions do we have about drones and how they work, or how they're used? Let's put them on the Driving Question Board and make sure our questions are organized by topic. *Procedure: Students call on each other, and each must explain how their question is related to the previous question. Afterwards, agree upon topics to group questions by, and then do so. Likely ideas will relate to the SSI question, electromagnetism, flight forces, or controlling/coding.*

Lesson 3 2 hours	Yesterday's work was a segue into the mechanics of energy and forces that result in flight. Now that we have set up our Driving Question Board, let's start to talk about it: What's energy? *Illicit student ideas, write them down. Use talk moves and ask students to explain their statements and respond to each others' claims.* According to the scientific definition from the US Energy Information Administration, **energy is the ability to do work**. In science, we only say work is done when something moves. Think-pair-share: So how does a controller get a signal through the air to a drone to make it move? *Students may think that it's because of an invisible force, and some might say it's energy waves.* Yes, it does have something to do with energy. We're going to investigate that today. We'll start by building our vocabulary, to add to our explanation toolbox. Half of the class will read The Electromagnetic Spectrum and the other half of the class will watch Radio Waves. Those of you who are curious and up for a challenge can watch How Does An Antenna Work? | weBoost. Be sure to take notes on what you're learning in your science notebooks. Then, each group will publicly share what they learned in a T-chart. Add pictures to support your ideas! Think-pair-share: How are the various wave types in the electromagnetic spectrum alike? How are they different? *Students will likely bring up the oscillation pattern, and also the differing wavelengths.* Use the Radio Waves and Electromagnetic Fields interactive simulation to try to figure out how the frequency and amplitude affect the structure and function of waves you see. What do electron positions in the transmitter and receiver tell you? Assuming a drone's receiver and a remote control's transmitter work the same way, use what you've learned to create a model that shows how waves were reflected, transmitted, and absorbed through various materials, from the controller to the drone, in order to tell it to move. You can use the Webb Space Telescope's *Behaviors of Light* diagram and the linked text to help you with your wave modeling. Add an entry about our research to the Progress Tracker.

Lesson 4 2 hours	We now understand how a signal travels. But we still don't know how a power source can make propellers move. What do you think is going on there? Think-group-share! *Students will likely talk about electricity coming from a battery, but many won't understand that a motor is responding to the electric current.* So, we need to explain what is pushing these stationary drone parts into action! It may surprise you. Half of the class will read electric fields and the other class will read magnet. Be sure to take notes on what you're learning in your science notebooks. Then, we'll publicly share what we learned in a T-chart. *If students do not elucidate the reflexive relationship between electricity and magnetism, add to their charts where necessary while doing some informational text metacognition practice in context.* Think-pair-share: How are electricity and magnetism related? How could we find out for ourselves? *Steer the conversation towards more controlled testing.* An investigation would help to answer this question. Two investigations would be even better! We are going to start with the PhET Magnets and Electromagnets simulation! It allows you to investigate the use of wire and battery to make a magnet as well as the interactions between a compass and a bar magnet. Fair tests need clear constraints. Let's chat! 1. Which variables impact magnet strength? How? 2. Which variables impact magnetic field direction? Why and how do the directions of fields change? *Students should mention distance and magnet or charge strength. If they don't, then point it out.* 3. How are bar magnets different from electromagnets? How do you know? 4. If the objects aren't touching, then what is making them move? How do you know? Now, use the Faraday's Lab interactive simulation and the Handout Investigation Plan to take time and figure out for yourselves how electricity and magnets are related in a propeller, with circular motion**.** *Note: You may choose to create your own electromagnets as a hands-on alternative, but it would be more difficult to collect and quantify data. More coils and a stronger current in a stationary magnet could be measured, as could the displacement of a magnet-strapped toy car (in response to the current), in a controlled investigation.* You must design the steps of your plan and carry it out in order. Make sure to record responses to the prompts as you go along. Did your experimental design help to explain how a battery that isn't in contact with a propeller can cause it to move? If the propeller isn't a magnet, then what's causing the rotation? Add an entry about our research to the Progress Tracker.

Lesson 5 1 hour	Now is the time when we look at which questions we've answered, and see what we still have to figure out. Our essential questions for the unit are: • Should the US military use combat drones? • How do EM waves control a drone? • How does a battery move a propeller? • How does a drone fly? We had lots of opinions on the military's use of drones, and these still need to be explored. But at this point, we do have a better idea of how a controller gets a signal through the air to a drone to make it move, even if we can't yet say why it flies. In order to get the details of the movement right, we need to follow the path of electricity from the battery. We'd see that there's a motor between the wires and propeller. So we need one more piece of information: How does an Electric Motor work? (DC Motor). Let's watch and take notes in a Notice-Wonder chart. *Students should connect their electromagnetism work from the last lesson to the non-contact forces observed in the motor. Find a student who wrote this down and ask them to share it with the class.* Now, in your groups, you'll put your lab work and models together to make an energy flow model that answers the question: How do the EM signals, electricity, and magnets actually cause the propellers to move? If you need help, here's another resource: Electromagnetism 101. *Big idea: Magnetic forces are caused by charged particles. Electromagnetic fields are formed when electrons flow between atoms.* After every group has completed its model, circle the most important ideas, and be prepared to share them with the rest of us. Now, we'll collaborate to create a consensus model that answers our question with everyone's ideas. *This model should show a signal transmitted from the remote to the drone's transceiver, a flow of electricity from the battery to the motor, electromagnetic repulsion in response to an alternating current, and propellers that rotate in sync with their respective motors. An advanced model will define magnetic poles and zoom in on magnetized atoms.* Add an entry to your Progress Tracker.

Lesson 6 2 hours	When we were last here, you all did some wonderful thinking about how the drones start to move. But can we explain how they fly? And what might it have to do with Newton's Laws? In your groups, do a quick model of the forces that might work together in order for moving propellers to lift a drone off the ground. Discuss: How might we find out for sure whether our models need revising? Do your models take the drone's mass into account? *Guide students towards the idea of testing forces scientifically, with a control and a variable.* Now, we have to learn about a combination of forces you may not have understood previously: lift, drag, weight, and thrust. And we can DEFINITELY run a controlled experiment to do so! Use the How Wings Work and Forces of Flight interactives to conduct an investigation that answers the question *How do the mass and parts of the plane affect the sum of forces that cause it to fly or fall?* Use the Handout Investigation Plan to design an investigation. Be sure that the model and description that shows what you've learned at the end has labeled vectors that represent the unbalanced forces that result in flight. Think about the concepts of stability and change. *Students should conclude that a plane needs lift that is equal to or greater than the weight, and thrust that is equal to or greater than the drag, in order to change its motion and fly.* For an Exceeds Expectations score, be sure to include Bernoulli's Principle in your final explanation. You can use No One Can Explain Why Planes Stay in the Air, STEM LEARNING: Advanced Air Mobility: The Science Behind Quadcopters Reader—Student Guide or NASA's Dynamics of Flight Page to help you. *Students should explain that the upward curve of wings causes air to rush over them, which means that there is lower air pressure above the wing than below, and therefore an upward push.* Add an entry to your Progress Tracker.

Lesson 7 1 hour	Yesterday, you used a simulation to conduct an investigation into the unbalanced forces of flight. You created models to show what you'd learned. And as you know, models have their limitations. In this case, we've been working on screens and paper. So how might we add another dimension to these flight forays? *Guide the conversation toward building planes of our own.* Watch Red Bull Paper Wings World Final. Do you think we could do a competition of our own? How do you think planes that are designed to levitate might be different from those designed to go a distance? *Illicit student ideas. Because of the last lesson, they are likely to talk about proportions of lift to thrust.* In this case, we're going to do an engineering and design challenge, and you can choose to either race or do the aerobatics of floating over a "fanner." Which plane designs might be better suited to each task? Think-group-share. *Students are likely to talk about flat wide planes gliding better and long pointy planes being faster. Press students to explain their thinking about why these structures support these functions.* NASA's Jet Propulsion Lab made an engineering design rubric that might help us to fine-tune the work. The *Building a Model or Prototype* and *Testing and Evaluating the Design* sections will be most useful here. So, how should we set up our test course? *Guide students towards marking out distance and height lines in the room or hallway, and using stopwatches and meter sticks to collect flight data and identify "winners." Write the testing criteria and constraints on the board, to assist students in their planning.* Take a few minutes to partner up and decide which challenge you'd like to compete in. Sign up on the board! Then, with your partners, come up with a design must-have checklist, and come up with at least 3 design plans in your notebooks. After you've agreed on a top choice, take your sheet of copy paper, and get to folding. Watch Aerodynamics Explained by a World Record Paper Airplane Designer	Level Up	WIRED or Fun Acrobatic Trick Paper Airplane Tutorial - The Stunt Plane - Fold 'N Fly to supplement your initial ideas. After work time, agree on how to set up a data chart, run the tests, and choose the race and aerobatics winners. *Remind students that if time allowed, we'd reiterate our designs for optimal performance and test again.* Look carefully at the most successful designs in each category. What do they have in common? What did we learn about how form affects function in flight? Add an entry to your Progress Tracker.

Lesson 8 1 hour	So, we now know how flight works… but we don't really know how a drone flies. One way is via manual remote-control use! It's the moment you've been waiting for, and you don't even need a license. We're about to roll, pitch, and yaw. Read Roll, Pitch, and Yaw: What These Terms Mean for Drones and pages 10-17 of your CoDrone EDU user manual (see the image below). • In your notebooks, write down what each command means, and which remote control actions would result in that type of movement. *Note: Students should end up with remote control actions that align with the bulleted directions list below. Definitions are: pitch- move forward and backward, roll- dip to one side, and yaw- turn in place.* Now that you have an action plan, here's our orderly practice procedure: Count off into groups of 3. Line up in three lines. The front person in each line has the first turn. Tie back your hair if you need to. Wear safety goggles. You will power on your controllers and drones. Now, when I say go, these directions will be repeated: • Note the location of the Emergency Stop: Press and hold L1 and pull down on the left joystick. You will do this immediately if I tell you to. • Push away from yourself on the left joystick when I say, "Take off." • Push away from yourself on the right joystick when I say "pitch forward." • Push towards yourself on the right joystick when I say "pitch backward." • Push right on the right joystick when I say "roll right." • Push left on the right joystick when I say "roll left." • Push left on the left joystick when I say, "Yaw left." • Push right on the left joystick when I say, "Yaw right." • Push towards yourself on the left joystick when I say, "Land." The next person in each line moves to the front, puts on the goggles and ties back hair if necessary, and so on, until everyone has had a turn. Then, go to your seat to write what you wondered, did/noticed, and figured out about remote-controlled flight commands. Add an entry to your Progress Tracker.

<table>
<tr>
<td>Lesson 9
4 hours</td>
<td>So, how might you program a drone to change its behavior on its own?
It’s all about the code, which is what is sent from the controller to the drone to tell it how to generate lift and propulsion. This part of our project is where you independently write a code, and work in groups to help each other get those drones off of the ground!

While coding in groups:
Stay on task, everyone talks about the work
Show each other what you’re doing and help each other
Listen to one another’s ideas
Be prepared to share with the class
How do we do it? Start. Go through the <u>Beginner's Course With Blockly</u> and code for:
takeoff
directions
variables
conditionals
loops
lights
landing
Then, we’ll take turns writing our own custom sequences, running our programs safely, recording our runs on video, and sharing them with the class.

Whenever you’re flying, each of these roles must be filled:
code runner
manager (checks that flight path is clear, catches drone carefully if necessary)
videographer
code narrator
Be safe and have fun! Wear goggles, tie back hair, and stay alert! After each group’s members got to run a code, do a video marathon. Think-group-share: What were our successes? What might we do differently if we were to do this again? Add an entry to your Progress Tracker.</td>
</tr>
</table>

Lesson 10 1 hour	Do we finally understand how drones work? Let's talk about what we learned from coding that helps us to answer that question. Think-group-share. *Students are likely to say that some electronic message is sent to a drone, which responds accordingly to the contents of the message. They are also likely to be unsure about the mechanics of translation; this puzzling phenomena is reserved for the next unit on artificial intelligence.* Create a final model on paper that integrates what you've learned about wave properties and behaviors, electromagnetism, unbalanced forces, and drone mechanics to answer the question *How do drones fly?* Be sure to feature structure and function, and cause and effect. You may refer to any of your previous models, investigations, or other classwork to help you, but you may not use a computer. When the models are finished, we will publish them on the hallway bulletin board.
Lesson 11 3 hours	Drones are here to stay. Your final project component is to write a CER statement. ● Construct an argument from evidence about which applications drones are/aren't appropriate for, and why. Use the CER Checklist (*see Appendix*) to help you. ● Evaluate source materials using a CRAAP Checklist (credibility rubric). Choose sources that are appropriate to your point of view, and acknowledge known biases. Here are some different lenses that you may want to understand and argue the issue with: *Note: Offer students access to sources 58-onward from the Resources section of this unit.* If you finish early, form peer-review pairs and revise your work. After that, you could do more Blockly practice.
Lesson 12 1 hour	And finally, it's time to apply what you know in debate. **Should the US military use combat drones?** Have you changed your opinion from what it was at the start of this unit? What do you think now? Discuss this as a class in a circular seating arrangement. Add an entry to your progress tracker. Revisit the Driving Question Board and see what has been answered, and which questions we still have. Pull your own opinions and questions from the board and place them in your notebook. Be sure to write down how you've changed your thinking since the start of this unit.

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Appendix

Linked Science Standards (Retrieved November 7, 2023 from NGSS Standards):

MS-PS4-2 Evidence Statement: https://www.nextgenscience.org/pe/ms-ps4-2-waves-and-their-applications-technologies-information-transfer

MS-PS2-5 Evidence Statement: https://www.nextgenscience.org/pe/ms-ps2-5-motion-and-stability-forces-and-interactions

MS-PS2-2 Evidence Statement: https://www.nextgenscience.org/pe/ms-ps2-2-motion-and-stability-forces-and-interactions

Linked English Language Arts Standards (Retrieved November 7, 2023 from PDESAS):

ELA CC.1.4.7.W
ELA CC.1.4.7.C

Standards-Based Category	Exceeds Expectations (4)	Meets Expectations (3)	Approaches Expectations (2)	Does Not Meet Expectations (1)

Design- **<u>MS-PS4-2</u>.** Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.	Model of radio waves and their interaction with the air and other objects between a controller and drone, is detailed, correct, and exceptionally organized in terms of design, layout, and neatness. You explained how the structure of a drone and antenna relate to functions.	Model of radio waves and their interaction with the air and other objects between a controller and drone, is correct and organized in terms of design, layout, and neatness. You explained how the structure of a drone and antenna relate to functions.	Model of radio waves and their interaction with the air and other objects between a controller and drone, is attempted, though lacking in clarity or complete information about structures and function.	Model of radio waves and their interaction with the air and other objects between a controller and drone, is incomplete.

Knowledge- **<u>MS-PS2-2</u>.** Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.	You documented an investigation that answers the question *How do the mass and parts of the plane affect the sum of forces that cause it to fly or fall?* Your labeled vectors include lift, drag, propulsion, and weight. You addressed stability and change. You explained how Bernoulli's principle figures into flight.	You documented an investigation that answers the question *How do the mass and parts of the plane affect the sum of forces that cause it to fly or fall?* Your labeled vectors include lift, drag, propulsion, and weight. You addressed stability and change.	You documented an investigation that attempts to answer the question *How do the mass and parts of the plane affect the sum of forces that cause it to fly or fall?* You lacked clarity or explanation of stability and change. Your labeled vectors include lift, drag, propulsion, and weight.	You documented an incomplete investigation to answer the question *How do the mass and parts of the plane affect the sum of forces that cause it to fly or fall?* Your labeled vectors do not include lift, drag, propulsion, and weight.
Application- **<u>MS-PS2-5</u>.** Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.	You designed and documented an experiment to explain how a battery that isn't in contact with a propeller can cause it to move. You explained how the drone's motors work in your final statement.	You designed and documented an experiment to explain how a battery that isn't in contact with a propeller can cause it to move.	You designed and documented an experiment to explain how a battery that isn't in contact with a propeller can cause it to move, but you had some omissions or misconceptions.	You incompletely designed and documented an experiment to explain how a battery that isn't in contact with a propeller can cause it to move.

Process- ELA CC.1.4.7.W: <u>Obtaining, Evaluating, and Communicating Information</u> Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or not supported by evidence.	The CER cites 4 sources and assesses their credibility via the CRAAP test, also scores "Meeting" on the CER Rubric. The Progress Tracker was updated 9-10 times with correct and detailed entries, which explain what we did and what was learned.	The CER cites 3 sources and assesses their credibility via the CRAAP test, also scores "Meeting" on the CER Rubric. The Progress Tracker was updated 7-8 times with correct entries, which explain what we did and what was learned.	The CER cites 2 sources and assesses their credibility via the CRAAP test, also scores "Approaching" on the CER Rubric. The Progress Tracker was updated 6 times with entries, which explain what we did and what was learned, but display some misunderstandings or omissions.	The CER cites 1 source and attempts to assess its credibility via the CRAAP test, , also scores "Beginning" on the CER Rubric. The Progress Tracker was updated less than 6 times.

Presentation-ELA CC.1.4.7.C: Develop and analyze the topic with relevant facts, definitions, concrete details, quotations, or other information and examples; include graphics and multimedia when useful to aiding comprehension	You designed 3 paper planes and flew one in a fair test. Your group's drone presentation showed the full range of codes, and was narrated in detail. You participated in our debates enthusiastically. You spoke loudly and clearly during discussion. Your model was published.	You designed 2 paper planes and flew one in a fair test. Your group's drone presentation showed the full range of codes, and was narrated. You participated in our debates and discussion. Your model was published.	You designed 1 paper plane and flew it in a fair test. Your group's drone presentation showed most of the codes, and was narrated. You spoke aloud during whole-class discussion or debate. Your model was published.	You never designed or flew a paper plane. Your group's drone presentation was incomplete. You did not speak aloud during whole-class discussion or debate. Your model was not completed for publication.