It's a Bird! It's a Plane! It's Biomechanics!

Danielle Ingle[1]*, Ryan Bruellman[1], Erick Espana[1], Katherine Galloway[1], Tanner Anderson[1], Tricia L. Meredith[2], and Marianne E. Porter[1]

[1]Department of Biological Sciences, Florida Atlantic University

[2]College of Education, Florida Atlantic University

Abstract

Biomechanics is a discipline that draws from physics and engineering principles to understand the movement and structure of living organisms. It is highly interdisciplinary in nature and can be incorporated into general biology and ecology courses. In our lesson "It's a bird! It's a plane! It's biomechanics!", we encourage students to integrate science, technology, engineering, and math (STEM) knowledge when considering a variety of animals in flight. Our lesson begins by reviewing the forces that act on a flying object: gravity, lift, thrust, and drag. When an airfoil travels through air at increasing speed, gravitational forces are counteracted by the generation of lift forces on the under-side of the airfoil, enabling the foil to take flight. Flying animals use their wings as airfoils to create forward and backward strokes, allowing them to remain airborne like an airplane. As the lesson continues, we discuss how various kinds of drag forces act on foils. First, parasitic drag occurs when air strikes protruding surfaces and no lift is generated; therefore, flying animals with more streamlined surfaces are typically more successful than those more subject to parasitic drag. Next, induced drag is created when air under a foil spills over the tips, creating vortices that disrupt streamlined flow over the wings. To conclude the lesson, we discuss the various wing loads, sizes, and shapes of flying animals that enable them to move through their respective environments. Since air and water are both fluid media, many of these topics can also be applied to animals that "fly" through the water.

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Supporting Materials: S1. Flight teachable tidbit – Lecture slides

***Correspondence to:** Department of Biological Sciences, Florida Atlantic University, 777 Glades Rd, Boca Raton, FL 33431.

Learning Goal(s)

Students will:

- review the forces that act on an object in flight.
- review the principles and mechanics of an airfoil.
- understand wing design and wing relationships to total mass.
- think critically and apply flight principles to animals in their respective environments.

Learning Objective(s)

Students will be able to:

- identify and define forces that act on an object in flight.
- understand the definition of Newton's third law of motion, which states that with every action there is an equal and opposite reaction, and apply this principle to explain pressure differences and lift generation.
- generate hypotheses about animal flight efficiency based on examining morphology (anatomy).
- generate hypotheses correlating wing size and performance during flight.
- apply their understanding of wing designs and wing relationships to total mass.
- compare flight principles among animals to understand the co-evolution in several animal groups.

INTRODUCTION

Origin of the Lesson

Active learning has been established as an effective way to engage students with new information (1). Teachable tidbits are short activities that use active learning as the vehicle to enhance student comprehension of the material (2-4). Here, we used multimedia to create our teachable tidbit enabling students to visualize ideas while interacting with each other and their instructor about lesson concepts. In a graduate level animal locomotion course at Florida Atlantic University, students developed a teachable tidbit as part of their self-directed learning. These tidbits were tested within the graduate course, then field tested in an introductory research methodology class for students that were dual-enrolled in high school and college. Based on reviews from field testing, we developed this particular biomechanics-oriented teachable tidbit on flight, which can be used in introductory biology, animal biology, evolution, or ecology courses. Biomechanics is a discipline that stems from kinesiology, the study of human movement (5). While our literature searches yielded no online tidbit resources specific to the mechanics of flight, we did find, paired with a patent for a robotic fish, suggestions for interactive learning lessons on swimming mechanics (6). This lesson utilizes short activities, vector graphics, photographs, and videos to convey the core components of powered flight using mechanical and biological examples. The lesson facilitates student engagement through questions, "think-pair-share" exercises, and group discussions that encourage students to ask questions throughout the PowerPoint presentation and expand into their interests on the topic.

Context and Rationale

We have included a "Science Behind the Lesson" article (https://www.coursesource.org/courses/science-behind-the-lesson-its-a-bird-its-a-plane-its-biomechanics) to provide instructors with in-depth information from peer-reviewed literature spanning topics in evolution, physics, anatomy, physiology, and ecology. These sections will provide the necessary background information for each area of emphasis within the general tidbit. Flight has evolved in several lineages of animals including insects, birds, and mammals (7-13). This tidbit uses principles from physics and engineering and applies them to biological examples. The diverse lesson concepts range from big-picture biological topics such as evolution and ecology to engineering and physics related concepts of flight forces and wing dynamics. Conceptual questions also relate to examples that students may see on a regular basis (e.g. airplane flight). For example, when we presented our tidbit to students in the research methodology course, we made comparisons between different aircraft models and flyers in the animal kingdom, drawing from students' previous knowledge of airplanes and applying that to a biological example (Supporting File S1. Flight teachable tidbit – Lecture slides). Both the albatross (bird) and glider (aircraft) have long slim wings (high aspect ratio, which is the wingspan squared divided by the surface area) and low wing loading (total weight divided by the surface area of the wing) to facilitate gliding. We found that higher content relatability piqued student interest and held their attention throughout the lesson. By incorporating examples of both animal and man-made flyers, the principles involved in flight can be understood and appreciated by all students.

Intended Audience

This tidbit was field tested at the Florida Atlantic University High School on students in a dual enrollment research methodology course, called Exploring Research. This lesson can be easily adapted for introductory level or more advanced students and at various types of institutions. In particular, this lesson is suited for an animal locomotion unit in a general biology or an evolution course when discussing the coevolution of shape and function or in an ecology course when discussing habitat use.

Required Learning Time

The lesson plan includes the PowerPoint presentation and embedded active learning activities that take approximately 45 minutes to complete.

Prerequisite Student Knowledge

Prerequisite knowledge may include introductory biological principles and high school level physics, but all core concepts are discussed in the lesson plan. Students are encouraged to draw upon what they already know about the world and apply it to biomechanics-related examples.

Prerequisite Teacher Knowledge

Instructors should be comfortable discussing physics principles relating to flight in birds and airplanes and comparisons between airplane design and wing morphology. Instructors should also be able to engage students in critical thinking discussions on flight in animals and man-made objects beyond what is included in the tidbit. These are all discussed in the accompanying Science Behind the Lesson. Therein, the evolution, anatomy, physiology, and ecology of flying insects, birds, and mammals are explored in depth to facilitate an adaptive application of flight concepts to different classroom settings and focus areas.

SCIENTIFIC TEACHING THEMES

Active Learning

Students will engage in active learning throughout the teaching tidbit. At the beginning of the lesson, the instructor will ask questions that will stimulate student discussion about flight and its major concepts. Many questions throughout the presentation are geared towards asking students to share their predictions or thoughts on the question verbally or by selecting answers through a clicker-based response system. However, questions can be discussed via "think-pair-share" activities and group discussions to further class interaction. "Think-pair-share" exercises encourage students to spend a few minutes individually considering their take on a given prompt related to the material and then mutually sharing and comparing their thoughts in pairs. Questions on wing size, wing loading, and specific animal flight examples throughout the teaching tidbit are geared towards students brainstorming their thoughts in small groups. These questions encourage students to analyze concepts that were discussed in terms of human-made systems and apply them to animals. After small group discussions, students can share their thoughts and predicted outcomes with the class with the instructor providing feedback.

Assessment

Student learning can be gauged through formative and summative assessments. Questions at the end of the lesson can be answered through open class discussions on biological applications of flight. Assessment questions following the lesson are short answer questions and apply the concepts discussed between students and instructor during the teaching tidbit. These can be used for a homework assignment or exam questions.

Inclusive Teaching

The teaching tidbit is designed to include all participants through individual and group questions and discussion throughout the lesson. Everyday examples are used in the lesson so that all students can connect with the material. The activities suggested range from open discussion to "think-pair-share," which engages students with a variety of comfort levels with in-class participation. The graphics, photographs, and videos used are large and clear, making them easy to see, and all images are "free to use" from open sources online (Creative commons, Unsplash, and Wikimedia). Information in this lesson is presented both orally and visually so that those with different learning preferences are accommodated. While the lesson makes comparisons between aircraft and flying animals, the use of nature-based examples provides everyone in the classroom with the ability to connect to the material regardless of background.

LESSON PLAN

Teacher Supplies

Teachers need a projector to show tidbit PowerPoint slides (Supporting File S1. Flight teachable tidbit – Lecture slides). Teachers should also hand out clickers or ask students to bring them to class, and clickers should be set up to run simultaneously with the tidbit PowerPoint slides (Supporting File S1. Flight teachable tidbit – Lecture slides). Alternatively, students can use the iClicker app, or any available similar devices or software, to select answers throughout the presentation. iClicker can be used on Apple and Android smartphones, laptops, and tablets; if students are using this, instruct them to have it downloaded before the start of the activity.

Lesson Outline

This lesson serves to introduce students to basic concepts and mechanics involved in flight. The mechanics of animal flight are not as extensively studied as fixed-wing aircraft, and as a result many of our examples are based on airplanes. Human-made mechanical systems are very similar to biological systems and both employ the same physical principles and are often cross-referenced in explanation.

Before presenting the "It's a bird! It's a plane! It's biomechanics!" PowerPoint presentation (Supporting File S1. Flight teachable tidbit – Lecture slides), instructors should explain the following lecture question formats that students will see throughout the teachable tidbit. If a question is called "flying solo," students are expected to think about and answer the question on an individual basis. We found traditional hand-raising followed by student-teacher discussion to be effective for these questions. "Flock talk" questions denote class discussions, so instructors should assign groups of 4-6 people for these portions of the presentation. To add an element of fun and group pride, assign each "flock" as a type of bird (pelicans, hawks, pigeons, etc.). Finally, students either select a partner or have a partner selected for them in preparation for "think-pair-share" questions, and their partner can change with every new question. Instructors should remind students to prepare their clicker devices (or have the downloaded iClicker app ready) for questions at the end of the presentation.

Once the lecture begins, students are introduced to four lesson goals (slide 2):

1. Review the forces that act on an object in flight.
2. Review the principles and mechanics of a foil.
3. Understand wing design and wing relationships to total mass.
4. Think critically and apply flight principles to animals in their respective environments.

Students' understanding of flying and mechanics of achieving flight (slide 3) is gauged by asking how objects defy gravity and stay in the air. Students usually responded with a description that forces are responsible for maintaining flight. A follow-up to the first question asks specifically which forces are involved in flight (slide 3). Students usually know a couple of related forces; however, if they don't list all of the primary forces (lift, gravity, thrust, drag), the instructor can proceed to the next slide. The purpose here is mainly to gauge students' background knowledge on the principles of flight. Next, students will break up into their designated groups or "flocks" and be asked to discuss the role of wings in flight and how objects without wings, like hot air balloons and rockets, are still able to fly (slide 4). The correct answer to look for here focuses on accelerated air pushing up on wings, producing lift. Hot air balloons can fly because hot air is less dense than cool air, therefore the air that is heated under the balloon rises. Rockets become airborne when high speed exhaust gases coming out of the engine nozzle propel the rocket in the opposite direction. Here, the separate groups can discuss their thoughts with the rest of the class. Instructors will then define and review four basic forces that act on an object in flight (slides 5 - 9: lesson goal 1). Next, we review foils, their structure, and the associated flight mechanics (slide 10: lesson goal 2). An airfoil is the shape applied to aircraft wings to produce high lift forces and low drag forces. As the foil moves through a fluid (air or water) at high speed, it accelerates fluid downward, creating an equal and opposite lift force. Newton's third law of motion, which states every action is accompanied by an equal and opposite reaction, explains this phenomenon. Oncoming still-standing air is accelerated over the top of a moving airfoil in a downward direction causing an equal and opposite upward lift force on the wing. This acceleration of air also lowers the air pressure on the upper surface of the wing relative to the bottom surface.

The above principles were illustrated using examples involving airplanes. Students are then challenged to apply the ideas they learned above to flying species in the animal kingdom (slide 11). First, the instructor asks students to discuss in their groups (flocks) how flying animals produce thrust and maneuver through their environments. When student groups report back to the class, an example of a correct answer would be that planes and other aircraft produce thrust through an engine. More thrust accelerates the aircraft faster and creates more lift under the wing, resulting in a rise in altitude until opposing forces reach equilibrium. Less thrust will decelerate the object and result in lowering altitude. Flying animals do not have engines, so they produce thrust by flapping their wings. These animals will flap their wings faster to speed up and gain altitude, and they will flap slower to slow down and lower in altitude. They can also intermittently glide (without flapping), which is essentially slow, directed horizontal movement. Likewise, many aircraft can glide without needing to produce thrust from their engines! Students will learn that in the case of birds, lift forces are created with forward and backward wing strokes (slide 12). Teachers will show the video linked to youtube.com titled "How Bird Wings Work (Compared to Airplane Wings)." After the video, students are asked to pair up and discuss why birds fold their wings in the backstroke. The correct answer here is that folding wings back against the body reduce drag (that slows down the animal in flight) and streamlines the body, detailed in the next slide.

Birds fold up their wings in the backstroke to reduce one of the forces discussed earlier: drag. Examples on the slide relate to human breaststroke swimming and a frog swimming (slide 13). Instructors can add to these with another example that may be more common for their students. One example is the way air flows over a person's hand when they hold it out the window of a moving car. Here, students are asked to think about and answer individually why our arms recoil on the upstroke during breaststroke swimming. A satisfactory answer would be that air and water are both fluid mediums, therefore many of the same rules apply. In water, recoiling arms also reduces drag by streamlining the body.

The instructor then discusses the concept of parasitic drag with students and how streamlining the design of an aircraft, for example, greatly reduces any protruding surface area for air to strike and subsequently slow down flight (slide 14). Since this lesson incorporates animal biology, we suggest pointing out to students that parasitic drag in physics is separate from parasitic relationships (a parasite living off of a host) found in nature. This is a great place to point out to students that during flight, landing gear is retracted into a plane and birds keep their feet tucked during flight to reduce drag forces. Students are then shown two pictures of aircraft and asked to decipher which is more streamlined, and why, in their think-pair-share groups (slide 15). The correct answer is that the aircraft on the right is more streamlined because the body is contoured to have a thin nose and wings that are posteriorly-inclined (towards the back). In contrast, the aircraft on the left has a blunt nose shape with straight wings, support cables, and non-retractable landing gear that hit airflow at a perpendicular angle. The teacher then introduces concepts of induced drag to students, in which pressure differences on the tops and bottoms of wings produce trailing vortices (slide 16). When conditions are right, you can actually see them. Two videos (YouTube links are provided) showing vortices of air flowing around airplane wingtips are given. As a review, students are given a clicker (or iClicker app) question asking which listed factors influence flight (slides 17-20).

Now, the lesson begins to transition to application; students are guided to apply what they have learned to different foil shapes and sizes. The calculation and meaning of wing loading is described to students, and high and low wings loads are specifically detailed in relation to size and mass in airplane picture examples (slide 21: lesson goal 3). This ratio concept (total mass/total wing area) will be needed for the subsequent slides in the PowerPoint (slides 19-22). If students need more practice before moving on, they can practice sample calculations that they think of, in terms of different winged animals. A series of clicker questions prompt students to vote on whether the pictured bird of prey, gliding bird, bat, and penguins require high or low wing loads in their respective habitats (slides 22-25). These questions can be followed with a group/class discussion if needed. Students should think about not only the spaces these animals must fly in, but the food types they are most likely foraging for such as insects versus fish (lesson goal 4). Final concept questions (slide 26) challenge students to consider other variables that can potentially influence flight, such as wind and thermal currents. Using their new knowledge (slide 26), students are then asked to critically think about why bird flocks fly in V-formations and why this benefits them. An example of a correct answer here is that birds within the flock save energy when the vortices that shed from their wingtips (via induced drag) cancel out with the animal positions behind them, or further out in the "V." Ideally, this would create a situation in which only the outer wings of the birds at the extreme ends of the "V" would produce vortices, saving a lot of energy in the unit as a whole.

When field-testing the "It's a bird! It's a plane! It's biomechanics!" teachable tidbit, we did not have students answer post-assessment questions for a grade. However, we do recommend instructors have students answer 2-3 questions to submit for a grade after the lecture in order to ensure that students were able to grasp the objectives outlined in the lesson goals at the beginning of the PowerPoint. Some examples of questions that could be asked are:

- Name two of the forces that act on an object in flight.
- Describe the differences in air pressure on an airfoil in flight.
- Name one characteristic of something an animal could do in flight that an object such as a plane could not do.
- What is meant by the term "wing loading?"

TEACHING DISCUSSION

Lesson Effectiveness

The lesson incorporated accessible examples of airplanes and flying animals to describe the forces acting on an object and the resulting movement through a fluid media. This lesson served as an interdisciplinary platform for concepts in physics and biology and challenged students to think critically about the science behind powered flight. The students who participated in this tidbit seemed to enjoy the opportunity to interact with one another and with the instructor. Student performance and interest during this flight tidbit exceeded that of four other tidbits presented to students during field testing, which focused on other types of animal movement such as swimming and arboreal locomotion. Most importantly, the students learned the content and enjoyed this lesson, which can lend heavily to retention of the information. One limitation to our field testing is that we did not have a clicker system (or iClicker app) established for the presentation, therefore we asked students to raise their hands to select their answers. We did not record percentages of correct versus incorrect answers; however, we note that for each question, the majority of students responded correctly.

General Student Reaction

Students were engaged with interactive discussion and questions posed throughout the tidbit. The presentation offered a unique style of learning that resonated with and engaged the students. Both animal and human-made examples discussed throughout the teachable tidbit allowed students to identify with and grasp important concepts and kept many students interested. The strength of this lesson is leveraging student experiences and intuition of aero/hydro-dynamics, which are key concepts of movement in everyday life.

Possible Improvements or Adaptations

For optimal effective learning, we suggest pairing the lesson with classroom activities where students can work both individually and in groups. This lesson can be adapted by capitalizing on topics that are best suited for the students' academic level and to the course itself. For example, in an ecology course, the evolution of wing morphology in flying animals among various ecological niches may be an important area of focus for the lesson. Conversely, topics on the mechanics of flight can just as easily be expanded for a physics class. However, as the tidbit is adapted for each course, we suggest that time for further class discussions and homework assignments may improve understanding of the material. Additionally, a hands-on component could be added where students draw, model, or 3D print different wing shapes to test them as air foils and quantify the effects on aerodynamics. Additionally, students could be asked to create paper airplanes, using different paper densities and assess if the differences in materials will have an effect on the flight of the airplane.

SUPPORTING MATERIALS

- Supporting File S1. Flight teachable tidbit – Lecture slides

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Table 1. It's a Bird! It's a Plane! It's Biomechanics! Lesson Outline

Activity	Description	Time	Notes
Pre-Teachable Tidbit Presentation Set-up			
Group organization	Go over answer styles that will be presented during the teaching tidbit: • Flying solo • Flock talk • Think-pair-share • Clicker question	2 minutes	• Flying solo - Questions to be answered without discussion or clicker questions (unless altered by the instructor). • Flock talk – break students up into groups with 4-8 students. • Think-pair-share – assign student partners or have them select their own. • Clicker question – students will vote on multiple-choice questions individually. Alternatively, the iClicker app can be used on smartphones, laptops, and tablets. • If using the iClicker app, make sure students have it downloaded before the start of the teachable tidbit.
Class Session – Teachable Tidbit Presentation (Supporting File S1. Flight teachable tidbit – Lecture slides)			
Introduction (slides 1 and 2)	Introduce four learning goals for the lesson.	2 minutes	
Introductory questions (slides 3 and 4)	Stimulate discussion with questions.	5 minutes	• Flying solo (slide 3) • Flock talk (slide 4)
Introduce forces (slides 5 – 10)	Describe four forces (gravity, lift, thrust, and drag) and introduce airfoils and Bernoulli's principle.	8 minutes	
Flying animal application (slide 11)	Have students think critically about concepts covered in slides 1-10 and the application to flying animals	4 minutes	
Bird flight video and application (slide 12 and 13)	Discuss how birds create lift. Explain drag in bird flight and why the same principles apply for breaststroke swimming.	6 minutes	• Watch video "How Bird Wings Work (Compared to Airplane Wings) • Think-pair-share (slide 12) • Flying solo (slide 13)
Drag videos and concepts (slides 14 – 16)	Explain parasitic drag and streamlining. Define induced drag.	8 minutes	• Think-pair-share (slide 15) • Watch three video links (slide 16) demonstrating wing tip vortices
Checkpoint (slide 17)	Influences on flight	2 minutes	
Wing loading (slide 18)	Introduce and define wing loading.	2 minutes	
Wing loading application (slide 19 – 23)	Wing loading, flight performance, and "V" formation skeins	6 minutes	• Clicker questions (slide 19 – 22) • Flying solo (slide 23)
Total Time		~45 minutes	