Engaging Diverse Learners

A 5-day, standards-based instructional plan for teaching high school physics mechanics topics through the thematic study of drones

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In the design of the learning experiences, the ten components of the Individual Activity Authentic Science Rating (French & Burrows, 2018, p. 537) were used as guidelines, along with Yang and Baldwin's four categories of technology use strategies in integrated STEM learning environments (2020, p. 4). Objective action verbs were drawn from Table 1 of Sharunova et al. (2020, p. 990). Inspiration for the thematic approach to teaching physics through drones came from Schroyer's "nesting doll" idea (2013, para. 3), Dekker and der Valk's 1986 account of a thematic pre-university physics curriculum, and Reid's work in applying the basic principles of physics to drone flight (2020). Further inspiration for teaching approaches came from Delahunty and Kimbell's 2021 discussion of the need to shift integrated STEM teaching towards heutagogy, and the concept of "vicarious learning" in social learning theory (Wulfert, 2021). Finally, the idea for the specific context of a drone transport startup came from the "Safe Delivery" section of the Royal Academy of Engineering's "Drones: friend or foe?" lesson series (2020).

Instructional Plan

The series of five lessons that follows is designed to be used as a "capstone project" at the end of a unit of study on Newtonian mechanics. Details of the International Baccalaureate Physics course Topic 2 (Mechanics) on which the lessons are based are described by Seigel (2022), but the lessons could be used as part of any pre-university physics course. It is assumed that students will have already studied Newtonian mechanics for several weeks before starting this series of lessons, and are thus already familiar with the topics mentioned.

Lesson 1

Standard:	**Objectives:**	**Materials:**
IB Physics Topic 2.1 - Motion ● Distance and displacement ● Speed and velocity ● Acceleration ● Graphs describing motion ● Equations of motion for uniform acceleration ● Projectile motion ● Fluid resistance and terminal speed	● *Apply* equations of motion in the context of drone movement in one and two dimensions ● *Develop* motion graphs for likely drone flight paths and *justify* choices of values with calculations	A toy drone such as the LiteBee Brix III would be useful to have available for students to examine (ideally a class set), but clear video examples of drone flight paths will suffice. Other than this, all that is needed are laptops with presentation and graphing software.
	Teacher Role(s)	**Student Role(s)**
Introduction (30 minutes) Students are introduced to the context of the project. They work for a hypothetical startup (which they can choose a name for) that is aiming to compete with Uber in the drone transport space. They are aiming to develop a versatile drone application that can deliver both people and relatively fragile cargo to horizontal surfaces AND deliver packages to remote locations via airdrop. Students will form project teams and research existing companies and applications.	● Provide suggested websites such as Volocopter for groups with weak research skills ● Give suggestions for important information to record about competitors' products (range, weight, battery capacity, etc). Remind students that the aim is to gather ballpark figures for order of magnitude calculations	Choose project teams, start a project file and record relevant information found on competitors' websites. Weaker groups may need to be given a template for recording data.
Guided Practice (30 minutes) Students will use the toy drone specifications to perform some approximate calculations that will help them to develop likely motion graphs for its typical horizontal and	● Give students guidance on what data they will need to find or estimate in order to construct their velocity time profile graphs -	At this stage students should be focused on doing "back of the envelope" calculations in their notebooks, and not worrying about the

vertical movement scenarios. They will work with the toy drone values as they are learning to apply the physics concepts, and then scale those models to their own product later in the project.	range, package drop height, maximum speed, maximum acceleration and deceleration, etc. ● More capable groups could also investigate terminal velocity	technical details of how to digitally construct graphs. They will likely need to split the work among their team in order to calculate sufficient data values for the next activity.
Independent Practice (30 minutes) Students will create digital versions of motion graphs for typical movement scenarios of a toy drone using the values from calculations in the previous step. These will be saved for later use as templates when they attempt to demonstrate the feasibility of their own drone application.	● It is suggested to use Desmos to create the graphs; students should be familiar with the basics of plotting graphs from maths lessons, but may need to be reminded of how to create piecewise graphs by restricting domain and range	Students should split the work in a similar way to the previous step. They should compile their work into a slide deck or shared document with links to the Desmos files for later use and modification.

Lesson 2

Standard: IB Physics Topic 2.2 - Forces ● Objects as point particles ● Free-body diagrams ● Translational equilibrium ● Newton's laws of motion ● Solid friction	**Objectives:** ● *Calculate* the thrust and clamping forces needed for typical toy drone movements, masses and payloads ● *Test* the validity of drone motion and force models experimentally, and quantitatively *evaluate* the extent of their validity	**Materials:** For this lesson one toy drone and one Vernier force sensor (or similar) per group would be ideal; however, video analysis of a demo drone (or failing that, an online video of a drone) will suffice for achieving the objectives.
	Teacher Role(s)	**Student Role(s)**
Introduction (15 minutes) Students familiarise themselves with the operation of the toy drone while attempting to answer the question "what is your team's best estimate of the maximum acceleration, and how did you estimate it?". Alternative for classes without a set of toy drones: watch promotional videos on drone manufacturer websites and try to make order of magnitude estimates based on what is shown in the videos.	● Struggling groups can be directed to the videos on the LiteBee Brix III product page ● Ask students to consider why knowing maximum acceleration is important to designing drones	Students should stay in their project teams and "play" with the drones for a while. Let them try to figure out how to operate it and their own method of estimating acceleration Alternative version: students should add any research and calculations to their project file.
Guided Practice (30 minutes) Building on the work from Lesson 1, students will now estimate the thrust forces required to perform the manoeuvres and flight profiles investigated earlier. They will also be introduced to the need for a	● Help students make the connection between the accelerations found during the previous lesson and Newton's laws of motion ● Direct students to	Students should continue to divide the calculation work among group members and compile their results in their project file.

clamp to deliver airdrop packages, and asked to investigate the likely friction coefficients and clamp forces involved.	resources like this one to get friction data • More capable groups could also investigate fluid drag models	They will likely need to split the work among their team in order to calculate sufficient data values for their presentations.
Independent Practice (45 minutes) Students will attempt to verify the theoretical models of drone motion that they have been using thus far in their calculations experimentally.	• Remind students how to use force sensors and/or video tracking software, but let them devise their own ways of experimentally verifying calculations • More capable groups could experiment with ways varying payload and measuring the effect on performance	Larger groups should conduct experiments in parallel (for example, lift force measurement and video tracking), so that all students are engaged.

Lesson 3

<table>
<tr><td>Standard:

IB Physics Topic 2.3 - Work, energy and power
Kinetic energy
Gravitational potential energy
Elastic potential energy
Work done as energy transfer
Power as rate of energy transfer
Principle of conservation of energy
Efficiency</td><td>Objectives:
Compare the use of energy conservation methods in calculating motion parameters like force and acceleration with previously used methods (equations of motion, Newton’s laws)
Apply power and energy calculations to the design of drone applications</td><td>Materials:

No additional materials required other than those already used in previous sessions.</td></tr>
<tr><td></td><td>Teacher Role(s)</td><td>Student Role(s)</td></tr>
<tr><td>Introduction (15 minutes)

Discussion: the battery energy density problem. Students are given 5 minutes silent reading time to read one of these articles: Faith in batteries - Aerospace America We won't have electric airplanes until battery tech improves | Engadget And 10 minutes to discuss the following prompts in their groups: Will long distance, high payload electric flight be feasible in the near future? Explain why you think this. What other alternatives to fossil fuel-powered flight exist? How do they compare?</td><td>Listen to conversations and gently correct any obvious misconceptions Ask students to consider why most existing drones are small and short range</td><td>Each group should appoint someone to record the ideas that emerge from the discussion in their file.</td></tr>
</table>

Guided Practice (30 minutes) Continuing to build on the design calculations from Lessons 1 and 2, students will first verify the values from previous sessions using energy methods, and then estimate power requirements and battery size. They will also be introduced to the need for shock absorbers for landing, and asked to estimate the size of the springs in that system based on the likely landing speeds and payloads.	• Remind students to factor efficiency into their calculations • Students may need a primer on the electrical aspects of battery capacity and power calculations if they have not yet studied Topic 5 • More capable groups could also investigate how shock absorbers work and perhaps even choose suitable standard sizes from a catalogue	Students should continue to divide the calculation work among group members and compile their results in their file. They will likely need to split the work among their team in order to calculate sufficient data values for their presentations.
Independent Practice (45 minutes) Student project groups will add to and update the information in their slide decks from Lesson 1 based on their new and improved data.	• Remind students of the key things that potential investors and/or those responsible for project fund allocation will want to know - how much can it deliver, how far, how quickly?	Students should split the work in a similar way to the previous step.

Lesson 4

Standard: IB Physics Topic 2.4 - Momentum and impulse ● Newton's second law expressed in terms of rate of change of momentum ● Impulse and force–time graphs ● Conservation of linear momentum ● Elastic collisions, inelastic collisions and explosions	**Objectives:** ● *Compare* the use of momentum-impulse methods in calculating motion parameters like force and acceleration with previously used methods (energy methods, equations of motion, Newton's laws) ● *Apply* momentum-impulse calculations to the design of drone applications	**Materials:** No additional materials required other than those already used in previous sessions.
	Teacher Role(s)	**Student Role(s)**
Introduction (20 minutes) Video: The tyranny of the rocket equation | Don Pettit | TEDxHouston 2013 Project group discussion: ● In your own words, why is it so hard to get off the planet? ● How is this similar to the problem of drone design? How is it different? Optional further reading: Escaping the Tyranny of the Rocket Equation - Scientific American Blog Network.	● Listen to conversations and gently correct any obvious misconceptions ● Students may struggle to connect the second discussion point with the current unit. Remind students that propellers and rockets both operate on momentum exchange, and how energy density is critical in both applications.	Each group should appoint someone to record the ideas that emerge from the discussion in their file.

Guided Practice (30 minutes) Continuing to build on the design calculations from Lessons 1-3, students will first verify the values from previous sessions using momentum-impulse methods, and then estimate likely air flow rates through the rotors based on other known parameters. They will also be introduced to the need for a payload ejection mechanism for the airdrop application, and asked to consider how conservation of momentum might apply to the situation (and influence the design).	• Remind students to continue to factor efficiency into their calculations • Students may need a primer on the wind turbine equation and its connection to thrust of a propellor if they have not yet studied Topic 8 • More capable groups might be ready for John Reid's models of airflow through the rotors and could learn about the Bernoulli equation	Students should continue to divide the calculation work among group members and compile their results in their file. They will likely need to split the work among their team in order to calculate sufficient data values for their presentations.
Independent Practice (40 minutes) Further experimental work. Some groups may wish to conduct new experiments that have arisen out of new calculations, while others may want to continue or repeat previous experiments from Lesson 2.	• Continue to support students with using technology while allowing them to design their own methods. At this point you could consider guiding weaker groups so that they have some data to present.	Larger groups should conduct experiments in parallel (for example, lift force measurement and video tracking), so that all students are engaged.

Lesson 5

<table>
<tr><td>Standard:

IB Physics Topics 2.1-2.4

The MYP Design Cycle</td><td>Objectives:

● Synthesise knowledge of Topics 2.1-2.4 in the design of a unique drone delivery application.
● Justify design choices with calculations that use appropriate error margins and reasonable order of magnitude approximations.
● Predict the likely ranges of values for the performance parameters of the drone delivery application.</td><td>Materials:

No additional materials required other than those already used in previous sessions.</td></tr>
<tr><td></td><td>Teacher Role(s)</td><td>Student Role(s)</td></tr>
<tr><td>Introduction (15 minutes)

Discussion: first principles thinking. Students are given 5 minutes silent reading time to read one of these articles:

● First Principles: Elon Musk on the Power of Thinking for Yourself
● Why Elon Musk wants his employees to use an ancient mental strategy called 'first principles'.

And 10 minutes to discuss the following prompts in their groups:

● In your own words, what is first principles thinking?
● How could it be applied to the case of drone design?</td><td>● Listen to conversations and gently correct any obvious misconceptions
● Ask students to consider how this connects with the energy density problem (Lesson 3)</td><td>Each group should appoint someone to record the ideas that emerge from the discussion in their file.</td></tr>
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Guided Practice (30 minutes) Students will choose a niche application of drone delivery to target and justify their choice by researching existing applications. Students will then repeat the relevant design calculations that they practised during Lessons 1-4 (using toy drone values) and update their results with estimated values required by their chosen application.	● Remind students to continue to factor efficiency into their calculations and allow some margin for error. ● Remind students that precise design calculations are not required - the aim is simply to verify that their proposed application is feasible based on the laws of physics. ● Guide students in choosing suitable approximate values where necessary	Students should continue to divide the calculation work among group members and compile their results in their slides. They will likely need to split the work among their team in order to calculate sufficient data values for their presentations.
Independent Practice (45 minutes) Student project teams will refine their slide decks further with the updated values that they calculated for their particular applications, in preparation for a near future event in which they will present their proposed solutions to a mock panel of investors. Ideally this would include one or more industry representatives but at the very least would include science, design and business management teachers.	● Remind students of the key things that potential investors and/or those responsible for project fund allocation will want to know - how much can it deliver, how far, how quickly? ● Remind students of the iterative native of the design process and that when they make a decision to change the size of one part of the system, it will likely have a knock-on effect on other parts of the system.	Students should split the work in a similar way to the previous step. They should plan their presentations so that each team member speaks roughly the same amount.

Conclusion

Engaging in a capstone project such as the one described in the paper near the beginning of students' study of the International Baccalaureate physics course will require an investment of lesson and planning time, but the potential upsides are many. By experiencing all the elements of authentic learning best practice early on in their studies, students will not only be more likely to remain engaged for the rest of the two-year course, but will also be more likely to pursue a STEM major at university. This is because they will have had a positive experience in science learning well before their university applications are due.

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