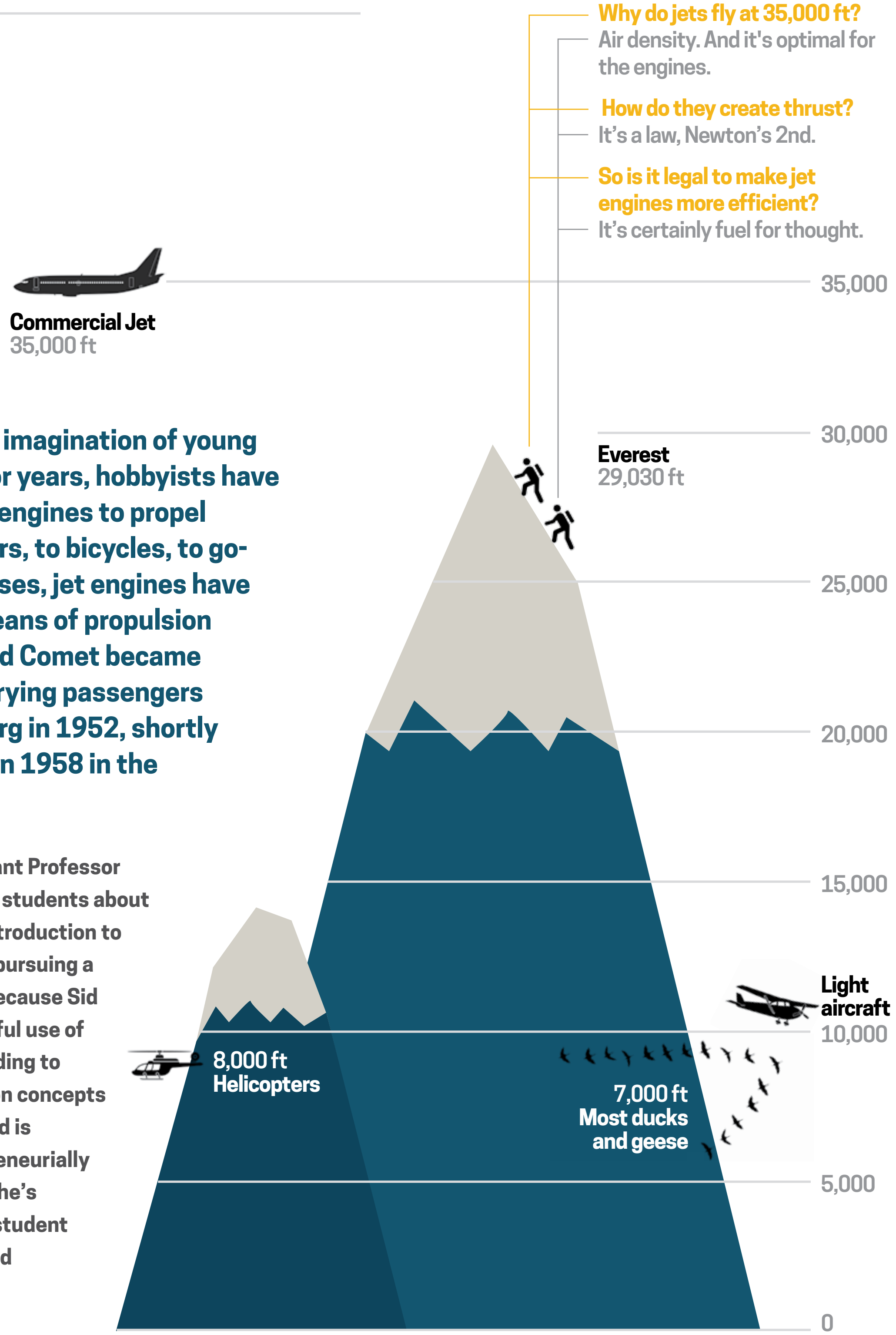
Getting EML Off the Ground

Why Do Jets Fly So High?

Jet engines capture the imagination of young and old people alike. For years, hobbyists have experimented with jet engines to propel everything from lawn tractors, to bicycles, to go-karts. For commercial purposes, jet engines have dominated the skies as a means of propulsion for 65 years. The de Havilland Comet became the first commercial jet, carrying passengers from London to Johannesburg in 1952, shortly followed by the Boeing 707 in 1958 in the United States.

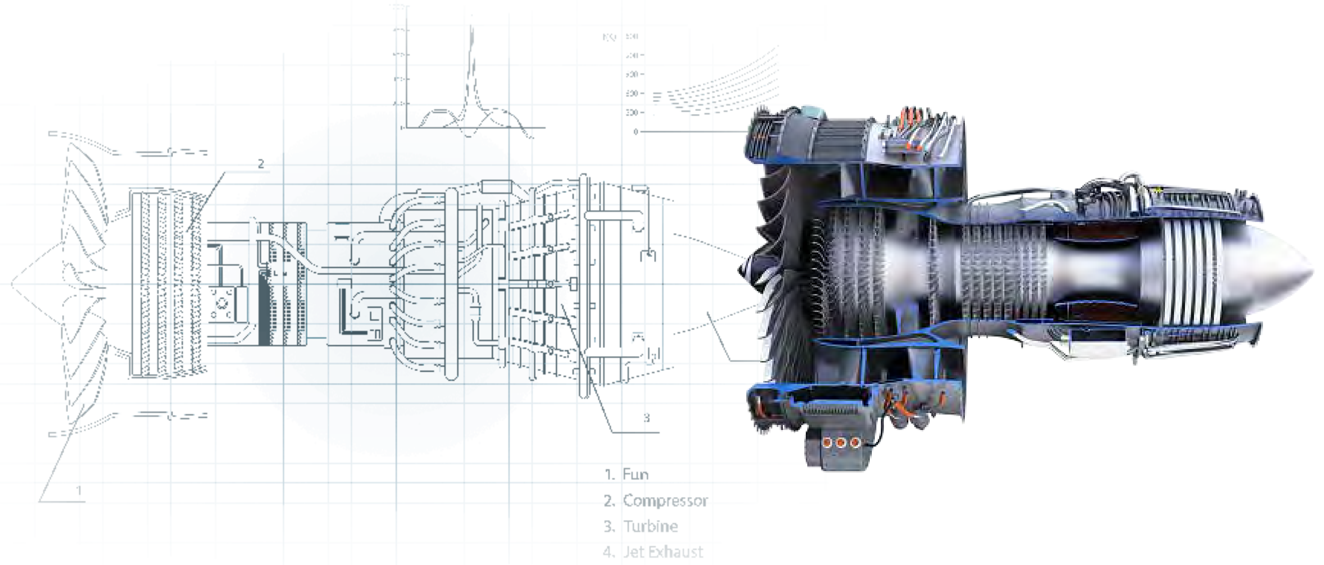
At the University of Dayton, Assistant Professor Sidaard Gunasekaran (Sid) teaches students about propulsion and flight. His course, Introduction to Flight, is designed for sophomores pursuing a degree in aerospace engineering. Because Sid believes that engineering is the artful use of resources and scientific understanding to create value, his instruction relies on concepts taken from the KEEN Framework. Sid is methodically incorporating entrepreneurially minded learning (EML). In addition, he's found methods of assessing KEEN student outcomes, both for assignments and the entire course. This article walks through how he does it.



Why do jets fly at 35,000 ft?
Air density. And it's optimal for the engines.

How do they create thrust?
It's a law, Newton's 2nd.

So is it legal to make jet engines more efficient?
It's certainly fuel for thought.



Let's talk about a jet engine's *thrust*, the driving force behind powered flight. What should a student in an introductory course remember, understand, analyze, or even create? These are traditional questions that an educator asks when using Bloom's Taxonomy to design a course and its learning outcomes.

As a sampling of learning outcomes organized by Bloom's, you might expect your students to:

- ➤ **REMEMBER** Newton's second law and the equation of thrust.
- ➤ **UNDERSTAND** how combustion and the Brayton cycle create pressure and velocity differentials that result in thrust.
- ➤ **APPLY** an understanding of Brayton's cycle to solve back of the chapter homework problems.
- ➤ **ANALYZE** which type of jet engine produces greater thrust.
- ➤ **EVALUATE** the contribution of each component to the thrust produced.

These outcomes are distributed across levels of Bloom's, which is good. **But where is the EML?**

Student learning outcomes become more meaningful by focusing on *opportunity* and *impact* and using instructional methods that animate the 3C's (curiosity, connections, and creating value). This is the core of EML. By augmenting the traditional learning outcomes, the key principles in the course become contextual, relevant, and interconnected. The teaching methods promote curiosity and creativity.

Inspect the following additions and consider how they embody EML:

	Original Learning Outcomes	Additional Outcomes for EML
Remember	Newton's second law and the equation of thrust	The nominal thrust of a large modern commercial jet engine, and the approximate cost, lifetime, and fuel consumption
Understand	How combustion and the Brayton cycle create pressure and velocity differentials to produce thrust	How components (inlet, diffuser, compressor, combustion chamber, turbine, and nozzle) are interconnected and contribute to thrust Why cruising altitude is an important parameter for optimizing efficiency
Apply	An understanding of Brayton's cycle to solve the "back of the chapter" homework problems	An understanding of engines to devise a laboratory experiment, measuring thrust of a simple electric fan with force sensors
Analyze	Which type of jet engine produces greater thrust	Which type of jet engine produces greater thrust/cost
Evaluate	The contribution of each component to the thrust produced	Opportunities to increase thrust with an assessment of both *feasibility* and *viability*
Create		A better electric fan (increased thrust)

Fueling Curiosity

The additional EML outcomes are effective when naturally integrated and woven throughout the technical topics. For example, calculation of thrust from a jet engine involves students plugging numbers into the following equation:

$$T = \dot{m}V_{exit} - \dot{m}V_{inlet} - (P_{inlet} - P_{exit})A_{exit}$$

where $\dot{m}$ is the mass flow rate, V_{exit} is the velocity at the exit, V_{inlet} is the velocity at the inlet of the engine, P_{exit} and P_{inlet} represent the exit and inlet pressure of air, and A_{exit} is the nozzle exit area. Given the inputs to the equation, it is straight forward to pose a question where the students calculate the value of thrust from an engine.

But modifying the posed question as:

- **"Can you identify opportunities to increase the thrust from the engine?"**

causes the students to think critically about the equation, analyzing each term, causing them to eventually realize why the different component of engines exists. While no connection has yet been made between the equation and the engine's components, students transform the parameters into meaning without Sid exposing them to the different parts of the engine.

They first see that the terms, $\dot{m}V_{inlet}$ and $(P_{inlet} - P_{exit})A_{exit}$, represent a thrust reduction. Students think about "How to increase the mass flow rate $\dot{m}$ and the exit velocity V_{exit}," while wondering three things: "What is causing this reduction?," "What is the physical meaning behind $\dot{m}V_{inlet}$?" and "What is the physical meaning behind $(P_{inlet} - P_{exit})A_{exit}$?" Through brainstorming sessions, students dive into an understanding of these terms in the equation and start to make *connections* between the equation and real life.

Cruising with Connections

Connecting first term with the jet engine

One of the ways to increase $\dot{m}$ is by increasing the size of the engine. While that is simple enough, increasing the size of engines has inherent disadvantages such as, adding weight, mounting, and maintenance. On the other hand, they can choose to increase the exit velocity. But how to increase the exit velocity of a jet engine? This provides a good opportunity for Sid to introduce conservation of mass and the relationship between the area and velocity. Through this approach, students will realize one of the reasons why nozzles are important in jet engines.

Connecting second term with the jet engine

Looking at the second term, $\dot{m}V_{inlet}$ physically represents the momentum of air coming into the engine. As the engine propels the aircraft faster, the air enters the engine at higher speeds, hence there is an increased air momentum at the inlet which results in reduction in thrust (also known as "ram drag"). Now the students may realize that pushing the incoming air faster toward the back of the airplane doesn't result in increase in thrust as stated by Newton's third law. It is the net momentum difference between the inlet and the exit momentum which creates thrust as stated by Newton's second law. As the engine performs work to push the air to higher speeds at the exit, it also needs to do work to slow down the incoming air thereby maintaining the momentum difference which results in thrust. With this newfound realization, students will be asked to begin thinking about how they might slow down the incoming air.

Connecting third term with the jet engine

Now considering the last term, $(P_{inlet} - P_{exit})A_{exit}$, it will be obvious for the students to see that when the inlet pressure equals the exit pressure, the terms go to zero, and as a result, the thrust will be maximized. The students can make the connection that when the air exiting the engine has the same pressure as the ambient pressure, then the thrust can be maximized. But how to achieve that? By now, students already know that a converging cross-section will result in an increase in velocity under subsonic conditions. This stage provides a better opportunity to introduce the relation between pressure and velocity (Bernoulli's equation) and also to teach students about the importance of nozzle performance and its impact on thrust with respect to altitude.

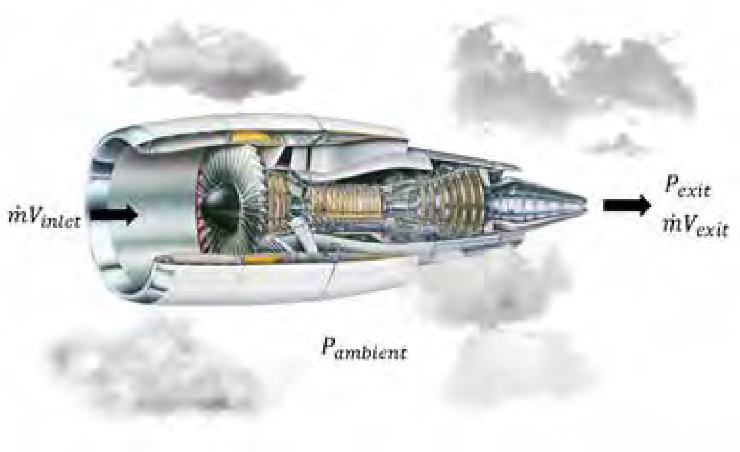
Landing with Values

With an understanding of these rudimentary ideas, students are ready to discuss opportunity, impact, and value-related questions.

Some students will choose to focus on opportunity. They know that the ambient pressure decreases with altitude and affects the thrust produced. The students start asking questions, "How can the nozzle be better designed so that the engine operates efficiently at any altitude? Is it possible to design such an engine? Are there new, enabling technologies?"

Other students may focus more on impact. "What is the environmental impact of jet engine exhaust? What are the societal impacts due to noise from jet engines? What are the current problems industries are working on?"

When using this method of instruction, Sid believes students naturally begin asking the above questions. It is amazing to realize the amount of knowledge, design details, and student-centered inquiry available from a single equation.



Turning on the Afterburners

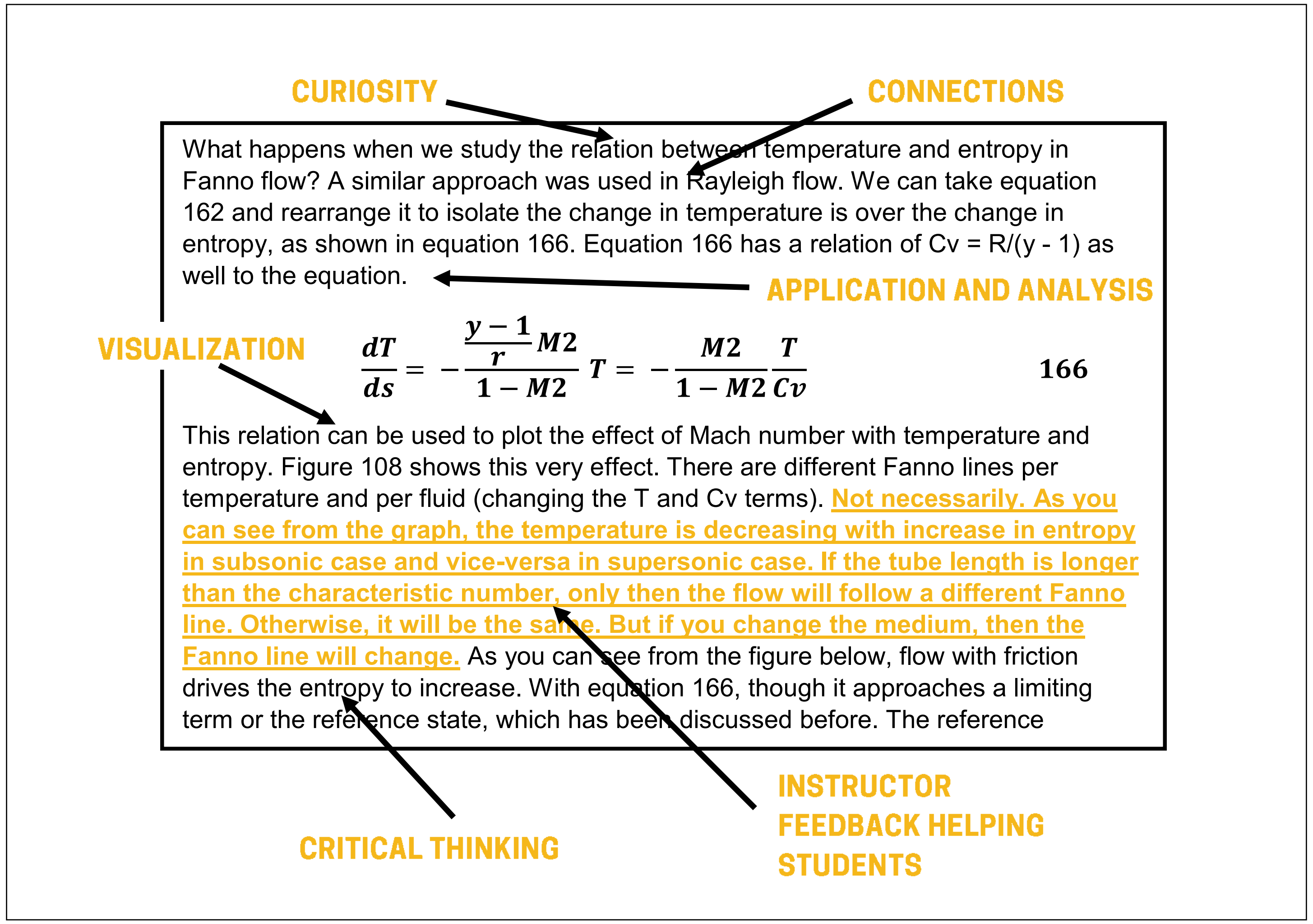
Sid uses portfolios to assess student learning. According to Bloom's, in order to facilitate lifelong learning, the evaluation methods should require the students to reflect, realize, synthesize, and critique. Exams alone are inadequate. This is where a portfolio-based evaluation system proves to be useful, to both the instructor and student. It provides a platform where students can integrate the subject matter they learned from different aspects of the course:

- **Lectures**
- **Homework assignments**
- **Projects**
- **Group discussions**
- **Independent studies**
- **Article summaries**

While the portfolio is specifically for the course, Introduction to Flight, students also discuss the technical content taught in different courses. In their portfolio, they connect homework assignments, projects, and concepts to other courses.

Metaphorically, these different aspects of the course are like pieces of puzzles which the students have to put together the way *they* understand the subject — and not the way it was taught by the instructor. As such, the completed puzzle in their portfolio is unique to each student in the course and reflects understanding and knowledge of the student in a way that an exam cannot.

The portfolio also provides a direct means to assess KEEN's 3C's. It has become a preferred method of course assessment in several of Sid's courses. An example paragraph is shown below, taken from a student's portfolio in his Compressible Flow course. Several elements such as curiosity and connections are clearly observed.



What happens when we study the relation between temperature and entropy in Fanno flow? A similar approach was used in Rayleigh flow. We can take equation 162 and rearrange it to isolate the change in temperature is over the change in entropy, as shown in equation 166. Equation 166 has a relation of Cv = R/(y - 1) as well to the equation.

$$\frac{dT}{ds} = -\frac{\frac{y-1}{r}M2}{1-M2}T = -\frac{M2}{1-M2}\frac{T}{Cv} \qquad 166$$

This relation can be used to plot the effect of Mach number with temperature and entropy. Figure 108 shows this very effect. There are different Fanno lines per temperature and per fluid (changing the T and Cv terms). Not necessarily. As you can see from the graph, the temperature is decreasing with increase in entropy in subsonic case and vice-versa in supersonic case. If the tube length is longer than the characteristic number, only then the flow will follow a different Fanno line. Otherwise, it will be the same. But if you change the medium, then the Fanno line will change. As you can see from the figure below, flow with friction drives the entropy to increase. With equation 166, though it approaches a limiting term or the reference state, which has been discussed before. The reference

Example paragraph from a student's portfolio in a Compressible Flow course.

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For additional information see: Gunasekaran, S. (2017), "Integrated Teaching Model in Graduate Aerospace Classes: A Trial With Compressible Flow Aerodynamics." Paper presented at 2017 ASEE Annual Conference & Exposition, Columbus, Ohio. https://peer.asee.org/28546