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.

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.

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.

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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:

\[ T = \rho \cdot A_{\text{exit}} \cdot V_{\text{exit}} \left( \frac{V_{\text{inlet}} - V_{\text{exit}}}{A_{\text{exit}} - A_{\text{inlet}}} \right) \]

where \( \rho \) is the mass flow rate, \( V_{\text{inlet}} \) is the velocity at the exit, \( V_{\text{inlet}} \) is the velocity at the inlet of the engine, \( A_{\text{exit}} \) and \( A_{\text{inlet}} \) represent the exit and inlet pressure of air, and \( m_{\text{thrust}} \) is the net momentum difference between the inlet and the exit momentum. The students start asking questions, “How can the nozzle be designed so that the engine operates efficiently at any 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 start asking the above questions. It is amazing to realize the amount of knowledge, design details, and student-centered inquiry available from a single equation.

Cruising with Connections

Connecting first term with the jet engine

One of the ways to increase \( \rho \) 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 connections from different aspects of the course:

➤ Lec
group discussions
➤ Project
➤ Article summaries

Connecting second term with the jet engine

Looking at the second term, \( \rho \cdot A_{\text{inlet}} V_{\text{inlet}} \) 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, \( \rho \cdot A_{\text{inlet}} V_{\text{inlet}} \) 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.

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 portfolios, 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 3Cs. 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.

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

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