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Integrating T-Shaped Competency Models in Interdisciplinary Aviation and Engineering Education

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As rapid technological change disrupts the engineering workforce, engineering education must move beyond traditional discipline-siloed instruction toward models that cultivate both specialization and adaptability. This study examines how a T-shaped competency framework, combining deep technical expertise with broad interdisciplinary skills, can be integrated into engineering curricula as an alternative to conventional single-domain teaching approaches. Through a curriculum case study focused on electric propulsion and drone-based instruction in an online environment, we illustrate how simulation tools, CAD platforms, programming, and embedded systems can simultaneously foster vertical depth and horizontal breadth. Drones serve as integrative teaching platforms that merge mechanical, electrical, and computational principles, enabling students to develop cross-functional competencies not typically emphasized in traditional curricula. Rather than a controlled comparison, the study demonstrates how the T-shaped model can enhance curricular agility and student preparedness for technological disruption. The findings suggest that embedding interdisciplinary, technology-rich learning experiences within a T-shaped framework may better equip engineering graduates to adapt to evolving workforce demands than conventional discipline-centric models.

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Introduction

The rapid pace of technological advancement is transforming the engineering landscape, creating both opportunities and vulnerabilities in workforce preparedness. Emerging forces such as artificial intelligence (AI), electrification, and the growing emphasis on sustainability are fundamentally reshaping the required skillsets for engineers and technologists. These pressures are contributing to what many experts refer to as skill disruption, the phenomenon in which previously valued competencies become obsolete or insufficient due to shifts in technology and industry demands (World Economic Forum, 2020; Fard et al., 2022). Engineers must now be prepared not only to master evolving technologies but also to transfer and reapply their skills across emerging domains.

In response to these challenges, the *T-shaped skills model* has gained traction as a framework for building a more adaptive and future-ready workforce. This model emphasizes a combination of *deep disciplinary expertise*, the vertical bar of the “T”, with *broad, cross-functional knowledge and soft skills*, the horizontal bar (Caputo et al., 2023). T-shaped professionals are able to innovate within their area of expertise while effectively collaborating across disciplines and responding to unfamiliar challenges. For engineering education, this means preparing graduates who can combine technical depth in fields like propulsion, robotics, or systems modeling with horizontal competencies in areas such as data literacy, sustainability, communication, and digital tools.

Multi- and interdisciplinary education has emerged as a key strategy to cultivate T-shaped learners. These programs intentionally integrate knowledge from multiple domains and often use project-based learning, collaborative problem-solving, and real-world applications to develop both depth and breadth in students' skillsets (Borrego & Cutler, 2010). In this context, students are not only trained in traditional technical knowledge but are also exposed to systems thinking, ethics, environmental impact, and the social dimensions of engineering innovation. Such an approach fosters *resilience*, the capacity of learners to adapt to shifting technologies, industry needs, and career paths over time.

This paper explores how *interdisciplinary integration of emerging technologies* into engineering curricula can support the development of t-shaped competencies and help prepare students for rapid technological change. Specifically, we examine how combining technical depth in areas such as propulsion, robotics, or energy systems with broader skills in programming, sustainability, and design can build a more resilient and adaptable engineering workforce. This approach encourages students to connect knowledge across disciplines, navigate complexity, and continuously learn as industries evolve.

To illustrate this framework in action, we present a case study involving the integration of *electric propulsion and uncrewed aircraft systems (UAS)* into an online engineering curriculum. This example demonstrates how drones and simulation-based platforms, such as CAD tools and propulsion modeling, can foster both vertical expertise and horizontal fluency. By applying the t-shaped model within an interdisciplinary educational setting, the case study highlights effective strategies for aligning technical instruction with the demands of an evolving workforce landscape.

Literature Review

The concept of *T-shaped skills* originated in the early 1990s and has since been widely adopted in business, design, and engineering education. Originally introduced by David Guest (1991) in the context of hiring more versatile computing professionals, the T-shaped model describes individuals who possess deep knowledge in a single domain (the vertical bar) and broad competencies across multiple disciplines (the horizontal bar). Tim Brown, CEO of the design consultancy IDEO, supported this assessment approach as a way to assemble interdisciplinary teams for creative collaboration. This blend of depth and breadth enables professionals to contribute specialized knowledge while also communicating and collaborating effectively across diverse teams (Johnston, 1978; Caputo et al., 2023; Oskam, 2009).

Recent research highlights the growing role of immersive technologies, adaptive learning systems, and interdisciplinary instructional platforms in preparing learners for rapidly evolving technological environments. Studies on virtual and extended reality demonstrate that well-designed virtual environments can significantly enhance engagement, experiential learning, and conceptual understanding across STEM disciplines, from K–12 contexts to engineering education (Ward et al., 2025; Barari & Sanders, 2025). In parallel, work on continual learning models in aviation systems emphasizes the importance of adaptability and lifelong learning in safety-critical, technology-driven domains, reinforcing the need for educational frameworks that support ongoing skill evolution (Barari & Barari, 2025). Project-based approaches using uncrewed aviation platforms further illustrate how complex systems such as drones can serve as integrative tools for teaching sustainable electric propulsion while bridging multiple engineering disciplines (Janke et al., 2025). Additionally, predictive analytics methods such as the FLASH framework have been applied to forecast student engagement in online engineering courses, demonstrating how data-informed instructional design can support persistence and success in digital learning environments (Barari & Sanders, 2025). Collectively, these studies underscore the effectiveness of technology-rich, interdisciplinary, and adaptive learning approaches, principles closely aligned with the T-shaped competency model explored in this study.

In the context of engineering, the vertical dimension typically reflects core technical expertise (e.g., thermodynamics, fluid mechanics, propulsion, circuits, or control systems in mechanical or electrical engineering). The horizontal dimension includes transferable skills and adjacent domain knowledge, such as data analysis, sustainability, systems thinking, ethical reasoning, and digital literacy. T-shaped engineers are increasingly valued because they can operate effectively in interdisciplinary and rapidly evolving environments, respond to cross-functional challenges, and retool their skills over time (Ramaley & Zia, 2005; Johri & Olds, 2011).

Prior work in representation learning and cognitive systems has explored mechanisms for incremental concept formation and knowledge retention without catastrophic forgetting, a critical capability for adaptive intelligent systems. Research on sparse coding and linked dictionary representations demonstrates how structured feature learning can support robust knowledge acquisition across tasks (Barari & Kim, 2021). Subsequent studies on incremental visual concept learning further show how models can incorporate new information while preserving prior knowledge, addressing a longstanding challenge in continual learning (Barari et al., 2024; Barari et al., in press).

The call for more *interdisciplinary engineering education* has grown over the past two decades in response to the complex, multifaceted nature of today's engineering problems. Challenges such as climate change, electrification, automation, and global health demand integrative solutions that span disciplinary boundaries. As a result, educators are increasingly designing curricula that incorporate *project-based learning*, *real-world case studies*, and *team-based assignments* that engage students across multiple technical and social domains (Borrego & Newswander, 2010).

Several frameworks support the integration of interdisciplinary education. For example, *constructive alignment* strategies encourage instructors to connect course objectives, teaching methods, and assessments to both disciplinary and interdisciplinary outcomes (Biggs & Tang, 2022). Other models, such as CDIO (Conceive-Design-Implement-Operate) and ABET's student outcomes, encourage the incorporation of systems thinking, communication, ethics, and teamwork into engineering programs, core competencies in the horizontal arm of the T-shape. Emerging technologies, especially AI, advanced manufacturing, and electrification, are rapidly shifting what constitutes core skills in engineering. Studies by the World Economic Forum (2020) and McKinsey & Company (2021) predict that up to half of the skills currently considered essential for engineers will be obsolete by 2030. Consequently, the *resilience of engineering talent pipelines* has become a focus for educational leaders and industry stakeholders alike (Borg et al., 2021; Fard et al., 2022).

Skill resilience refers to a learner's ability to absorb, adapt, and pivot their capabilities as technical domains shift. T-shaped learning is particularly well-suited for this because it prepares students to retain a strong disciplinary identity while reconfiguring their competencies around new technologies or job functions (Ramaley & Zia, 2005). *Online and modular learning environments* further support this adaptability, allowing for dynamic updates to content, simulations, and learning platforms.

Technologies like computer-aided design **(**CAD**)**, simulation tools, and low-cost physical platforms (e.g., drones, sensors, Raspberry Pi kits) are increasingly used in engineering programs to bridge theory and practice. When embedded in a curriculum that emphasizes both disciplinary knowledge and cross-domain collaboration, these tools can powerfully reinforce the T-shaped learning model. For instance, drone platforms inherently combine principles from mechanical design, electrical systems, control theory, and computer programming, making them ideal for fostering interdisciplinary thinking (Palaigeorgiou, 2017).

Despite widespread agreement on the benefits of interdisciplinary education and T-shaped skills, *implementation challenges* remain. These include resistance from traditional academic departments, constraints on credit hours, and difficulties in assessing horizontal competencies (Borrego & Cutler, 2010). Nonetheless, pilot programs and case studies increasingly show how such integration can be successful, particularly when tied to emerging domains like electric aviation and uncrewed systems.

Research Questions

This study is guided by the following research questions:

1. How can the T-shaped skills model be used to enhance resilience to skill disruption in engineering education?
2. What role do interdisciplinary and online learning environments play in supporting the development of T-shaped competencies?
3. In what ways can drone-based instruction and electric propulsion concepts serve as effective platforms for integrating vertical and horizontal skill development in undergraduate engineering curricula?

To address these questions, the paper draws on a curriculum case study focused on the integration of electric propulsion and drone-based learning in an online undergraduate program. The study:

- Maps the T-shaped model onto course design, showing how depth (e.g., propulsion modeling, CAD, drone simulation) is balanced with breadth (e.g., programming, sustainability, systems thinking).
- Demonstrates how interdisciplinary tools and platforms, such as SIMNET, Raspberry Pi, and TinkerCAD, are used to engage students across mechanical, electrical, and computing domains.
- Analyzes curriculum features, including modular course templates, faculty development, and virtual labs, that support horizontal competency development in flexible, scalable ways.
- Reflects on the broader implications for designing engineering programs that prepare students to adapt as technologies and job roles evolve.

This work contributes to the growing body of evidence that multi- and interdisciplinary programs aligned with the T-shaped skills framework offer a strategic advantage in preparing students for future-ready careers.

Methodology

This study employs a qualitative curriculum case study approach to examine how a T-shaped competency framework can be implemented within an interdisciplinary engineering program. Rather than conducting a controlled experimental comparison, the research focuses on documenting instructional design, technological integration, and pedagogical practices associated with drone-based and electric propulsion instruction in an online undergraduate environment.

Educational Context

The case study is situated within an online engineering curriculum centered on uncrewed aircraft systems (UAS), robotics, and autonomous platforms. Courses are delivered through a learning management system using standardized templates that support modular content delivery, virtual laboratories, and project-based assignments. Students engage with simulation tools, CAD software, programming environments, and embedded systems platforms as part of regular coursework.

Data Sources

Evidence for the implementation of the T-shaped model was drawn from multiple instructional artifacts, including:

- Course syllabi and module designs
- Assignment descriptions and project requirements
- Student design projects and simulation outputs
- Instructor observations of student engagement and performance
- Documentation of learning tools and platforms used in instruction

These sources were analyzed to identify how vertical disciplinary depth and horizontal interdisciplinary competencies were embedded within course activities.

Analytical Approach

The analysis focused on mapping instructional components to the vertical and horizontal dimensions of the T-shaped competency model. Vertical development was assessed through activities emphasizing domain-specific expertise (e.g., propulsion modeling, CAD design, simulation), while horizontal development was examined through tasks requiring cross-domain integration (e.g., programming, systems thinking, sustainability considerations, teamwork). Rather than measuring outcomes quantitatively, the study evaluates the alignment between curricular design and the theoretical principles of T-shaped learning. Observed student behaviors, such as transferring knowledge across domains, integrating multiple systems, and adapting solutions to new contexts, were interpreted as indicators of interdisciplinary competency development.

Limitations

Because this work does not include a control group, standardized assessment instruments, or longitudinal outcome data, conclusions should be interpreted as illustrative rather than causal. The primary contribution of the study lies in demonstrating a feasible implementation model and identifying design principles that may support future empirical research on T-shaped learning in engineering education. Additionally, resilience outcomes were inferred from qualitative evidence rather than measured using validated psychometric instruments or longitudinal tracking, which limits the ability to draw conclusions about long-term adaptability.

The T-Shaped Model as a Framework for Resilience

In the face of accelerating technological change and industry transformation, engineering graduates must be equipped not only with specialized technical skills but also with the adaptability to shift across emerging domains. The T-shaped model provides a conceptual and pedagogical structure for achieving this balance. By combining *deep disciplinary knowledge* (the vertical axis of the "T") with *broad, cross-disciplinary competencies* (the horizontal axis), the model supports professional resilience that enables engineers to pivot when skillsets become obsolete, collaborate effectively across disciplines, and continuously integrate new knowledge.

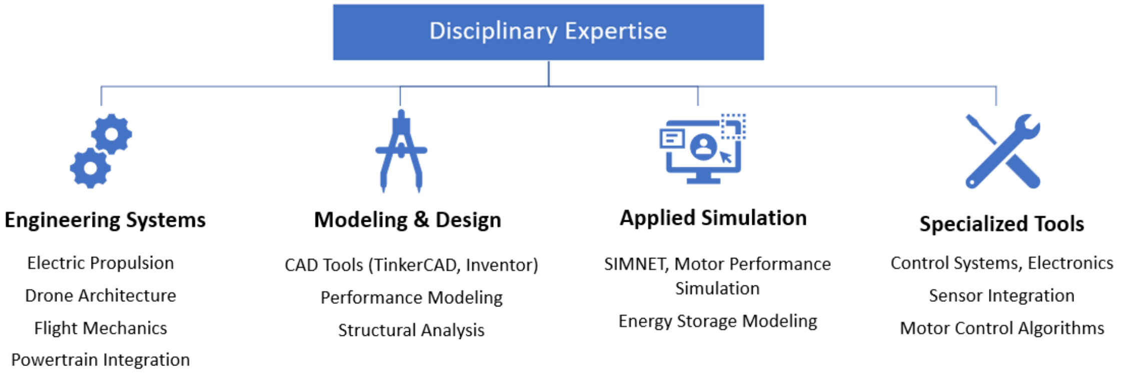
Vertical Depth: Technical Expertise in a Disciplinary Core

The vertical axis of the T-shaped model refers to a student's *core expertise*, the domain in which they can develop deep problem-solving ability, perform technical analysis, and apply advanced tools and methods. In the case study presented here, electric propulsion systems serve as the focal domain for vertical learning. Students engage in coursework and hands-on assignments that emphasize key technical components such as motor design, power electronics, propulsion modeling, and system integration. Simulation environments like SIMNET and CAD software platforms are used to model real-world engineering scenarios, giving students the opportunity to apply theoretical knowledge to practical design challenges.

This technical depth ensures that students build confidence in a core area, preparing them for entry into specialized career paths in aerospace, robotics, or electrical systems. It also serves as an anchor around which broader skill development can occur. **Figure 1** displays the breakdown of vertical expertise in the T-shaped model, highlighting four key domains, including Engineering Systems, Modeling & Design, Applied Simulation, and Specialized Tools, used to build deep technical proficiency in an interdisciplinary engineering curriculum focused on electric propulsion and drone technologies.

Figure 1

Disciplinary Expertise as the Vertical Depth of Our T-Shaped Model



Horizontal Breadth: Interdisciplinary Fluency and Transferable Skills

The horizontal axis of the T represents *generalist competencies* that cut across disciplinary boundaries. These include *computational thinking, sustainability awareness, communication skills, digital literacy, teamwork, and systems thinking*, all of which are increasingly in demand across technical fields. In the case study, students gain this breadth through assignments that integrate drone platforms with programming (e.g., Python), embedded systems (e.g., Raspberry Pi), and design thinking approaches using CAD tools like TinkerCAD.

Drones offer a particularly rich teaching platform for horizontal skill development because they inherently require the convergence of multiple fields: mechanical design, electrical control, software programming, and aerodynamics. This multidimensional learning experience fosters cognitive flexibility, encouraging students to draw connections between systems and adapt knowledge across new contexts, hallmarks of resilient professionals.

Figure 2
Cross-Functional Competencies as Horizontal Breadth of Our T-Shape Model

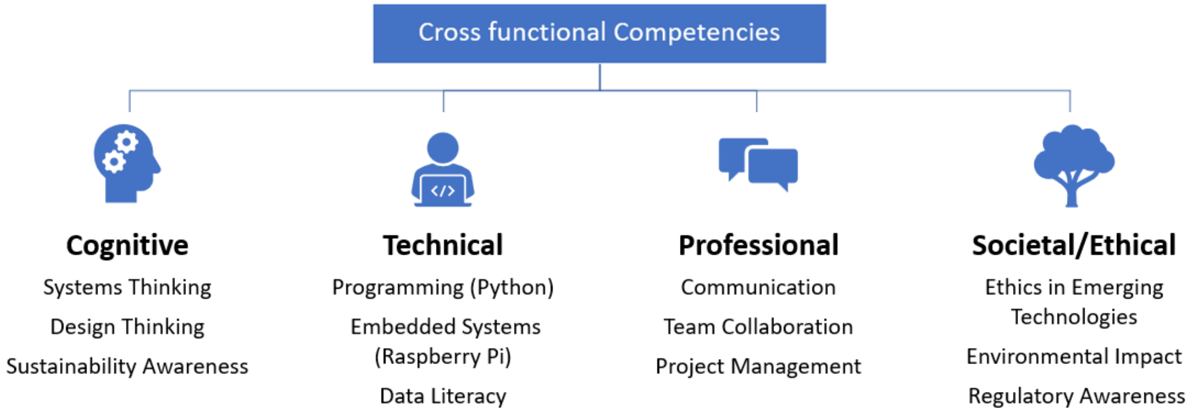


Figure 2 represents horizontal competencies in the T-shaped model, categorized into Cognitive, Technical, Professional, and Societal/Ethical domains. These cross-functional skills support adaptability, interdisciplinary collaboration, and resilience in engineering education. When combined, the vertical and horizontal dimensions form a foundation for resilience to skill disruption. A student with deep knowledge in propulsion who also understands data analysis, sustainability, and embedded computing is far better positioned to retool or shift their role in response to technological changes than a narrowly trained specialist. This kind of adaptability is essential in areas like electric aviation, where the technologies, regulations, and workforce requirements are still evolving.

Figure 3
T-Shaped Skill Profile

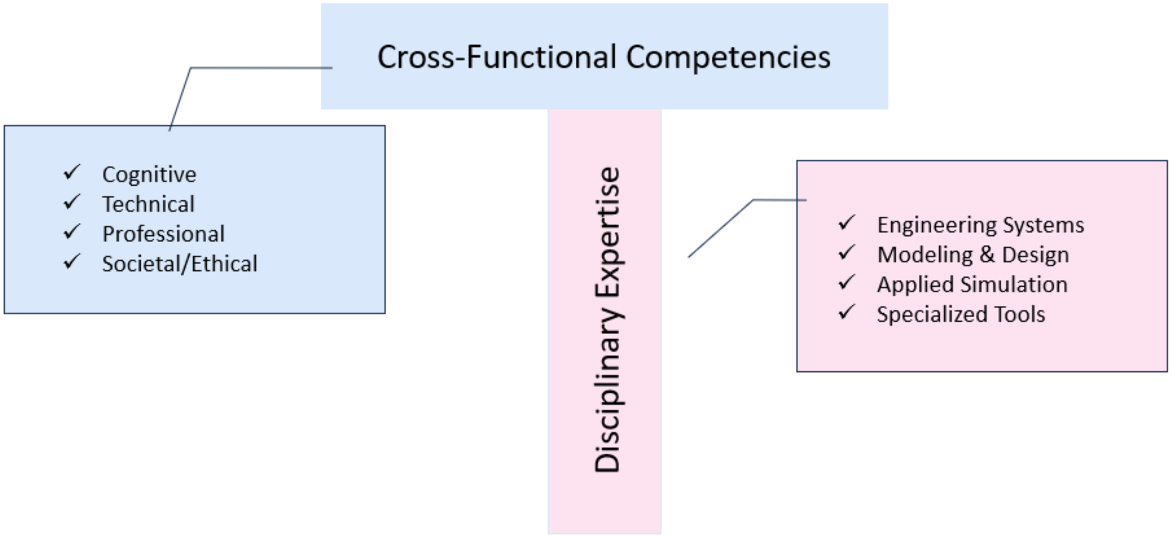


Figure 3 shows that the integration of vertical disciplinary expertise with horizontal cross-functional competencies creates the T-shaped skill profile, demonstrating an adaptable framework that equips students to navigate evolving technologies, interdisciplinary challenges, and future workforce disruptions in fields like electric aviation.

Resilience Through the T: Educational Design for Disruption

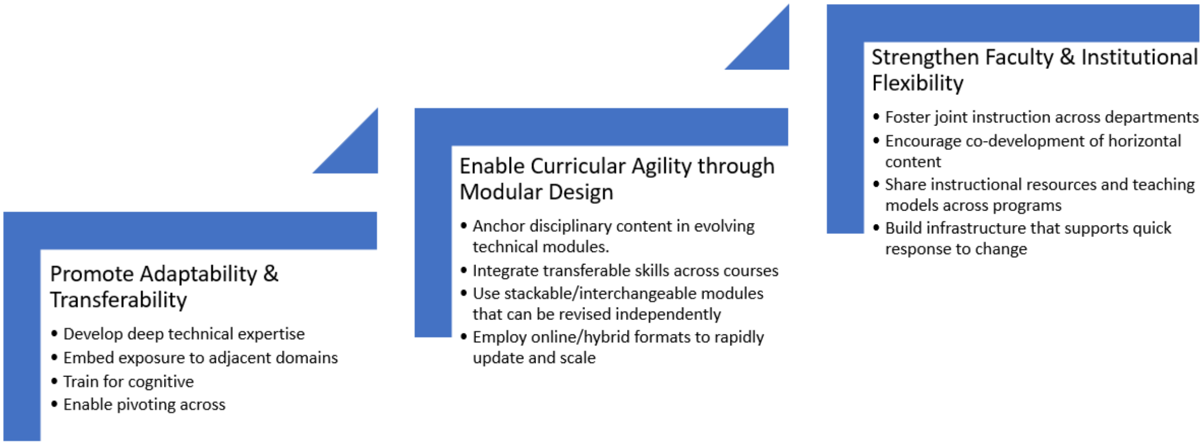
Designing a curriculum around the T-shaped model enables *curricular agility*. Because the horizontal dimension emphasizes broad competencies and transferable tools, new technologies or topics, such as AI integration, electric propulsion, or additive manufacturing, can be introduced with minimal structural disruption. Educators can scaffold new technical content atop a resilient, interdisciplinary framework.

Figure 4 demonstrates a three-step framework for implementing the T-shaped model in engineering education. This progression transforms the concept from an abstract ideal into a practical strategy for designing resilient, future-ready programs.

The following sections outline each of the three steps in detail, illustrating how they collectively support the integration of the T-shaped model into resilient and adaptable engineering program design.

Figure 4

Operationalizing the T-Shaped Framework through a Three-Step Path to Resilient Engineering Program



Promote Adaptability & Transferability

- Develop deep technical expertise
- Embed exposure to adjacent domains
- Train for cognitive
- Enable pivoting across

Enable Curricular Agility through Modular Design

- Anchor disciplinary content in evolving technical modules.
- Integrate transferable skills across courses
- Use stackable/interchangeable modules that can be revised independently
- Employ online/hybrid formats to rapidly update and scale

Strengthen Faculty & Institutional Flexibility

- Foster joint instruction across departments
- Encourage co-development of horizontal content
- Share instructional resources and teaching models across programs
- Build infrastructure that supports quick response to change

Resilience Through Adaptability and Transferability

The T-shaped model inherently promotes *resilience* by ensuring students are not limited to a single, narrow technical skillset. While the vertical axis develops their expertise in a focused area (e.g., electric propulsion, embedded systems), the horizontal axis exposes them to *adjacent fields, transferable tools,* and *systems-level thinking*. This balance helps students:

- *Pivot across roles or sectors* when technologies evolve.
- *Recognize patterns and analogies* across disciplines, improving problem-solving in unfamiliar contexts.
- *Reskill quickly*, as broad exposure reduces the cognitive load of learning adjacent competencies.

For example, an engineering student with vertical skills in drone propulsion can transfer that knowledge into roles involving robotics, automotive electrification, or renewable energy systems, especially when combined with their broad understanding of coding, design thinking, or sustainability.

Curricular Agility Through Modular Integration

The T-shaped model also provides a blueprint for *curricular agility*, enabling institutions to revise or expand programs without overhauling entire degree structures. This is achieved by:

- Anchoring specialized knowledge (vertical axis) in well-defined, evolving core modules (e.g., propulsion, mechatronics).
- Embedding cross-disciplinary themes (horizontal axis) like sustainability, AI literacy, or communication into multiple courses.
- Designing interchangeable or stackable modules that can be updated independently, especially in online or hybrid formats.

Because horizontal competencies (like Python programming or sustainability ethics) are relevant across many domains, they can be taught in *shared general education or interdisciplinary electives*, allowing instructors to revise content for emerging trends (e.g., AI-enabled control systems) without disrupting the vertical structure.

Faculty and Institutional Flexibility

From a programmatic standpoint, the T-shaped approach encourages *cross-collaboration among departments* (e.g., engineering, computer science, environmental studies), reducing silos and increasing the *agility of teaching teams*. For instance:

- A course in electric propulsion might involve joint modules on battery modeling (mechanical engineering), control systems (electrical), and Python programming (computer science).
- Faculty with different expertise can co-develop horizontal modules that are portable across programs.

This architecture allows institutions to *respond faster to industry demands*, accreditation changes, and new technologies without a complete redesign of curricula. When supported by such infrastructure, the T-shaped model can move from a theoretical framework to a practical guide for building robust, scalable engineering programs that are well-aligned with current and future industry needs.

Implementation of the T-Shaped Framework: A Case Study in Drone-Based Engineering Education

To operationalize the T-shaped competency model in engineering education, this study presents a case example in which interdisciplinary instruction on *electric propulsion* and *uncrewed aircraft systems (UAS)* is delivered within an *online learning environment*. This implementation demonstrates how curriculum design, technological integration, and pedagogical strategy can work together to cultivate both vertical technical expertise and horizontal cross-disciplinary competencies.

Curriculum Context and Course Design

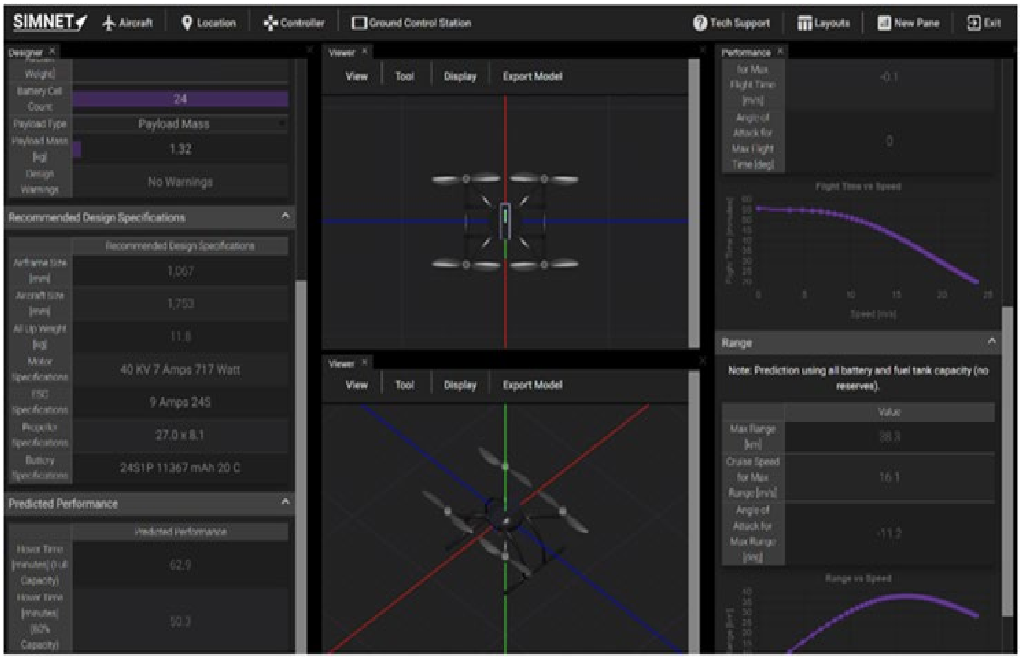
The course modules discussed in this case study are embedded in an undergraduate engineering curriculum focused on uncrewed systems and autonomous platforms. Instructional content draws from *aerospace propulsion*, *robotics, electrical systems*, and *CAD*, forming the vertical foundation of technical depth. To address horizontal competencies, the courses incorporate topics in *Python programming*, *embedded systems (Raspberry Pi)*, *systems thinking*, *sustainability*, and *project-based teamwork.*

Course delivery is facilitated through an online learning management system (LMS), where standardized templates allow consistent implementation of interdisciplinary content across multiple sections. This modular design enables rapid integration of new content without requiring large-scale curricular restructuring, supporting the kind of curricular agility envisioned in the T-shaped model.

Learning Tools and Platforms

The technical and interdisciplinary integration is made possible through a suite of hands-on and simulation tools, including:

- **SIMNET**: A drone simulation software that enables students to model electric motor performance, battery behavior, and aerodynamic loads.



Battery Cell Count	24
Payload Type	Payload Mass
Payload Mass [kg]	1.32
Design Warnings	No Warnings

Recommended Design Specifications

	Recommended Design Specifications
Airframe Size [mm]	1,067
Aircraft Size [mm]	1,753
All Up Weight [kg]	11.8
Motor Specifications	40 KV 7 Amps 717 Watt
ESC Specifications	9 Amps 24S
Propeller Specifications	27.0 x 8.1
Battery Specifications	24S1P 11367 mAh 20 C

Predicted Performance

	Predicted Performance
Hover Time [minutes] (Full Capacity)	62.9
Hover Time [minutes] (80% Capacity)	50.3

for Max Flight Time [m/s]	-0.1
Angle of Attack for Max Flight Time [deg]	0

Range

Note: Prediction using all battery and fuel tank capacity (no reserves).

	Value
Max Range [km]	38.3
Cruise Speed for Max Range [m/s]	16.1
Angle of Attack for Max Range [deg]	-11.2

Figure 5: SIMNET for drone simulation

An example from the aviation context is to provide students the opportunity to practice safety and risk management by using simulation software such as SIMNET, shown in Figure 5, to prepare for a UAS mission and conduct a pre-flight safety check under conditions and locations that mirror real-life flight scenarios.

- **TinkerCAD and Autodesk Inventor**: Tools used for conceptualizing and building aerial platform designs.

  CAD software continues to be a cornerstone of robotic platform engineering and development. Hence, drones, as aerial robotic platforms, can be excellently designed and visualized by such object and shape simulation software.

  A good start for students is educational software platforms that are free for educational purposes, such as the AutoDesk products of TinkerCAD and Fusion 360. The first provides an introduction and tutorial for CAD software in general, which is depicted with an exemplary drone design in **Figure 6**. It is also possible to introduce the taxonomy and topology of a drone platform according to a color code (**Figure 7**, TinkerCAD).

Figure 6
Autodesk Fusion 360

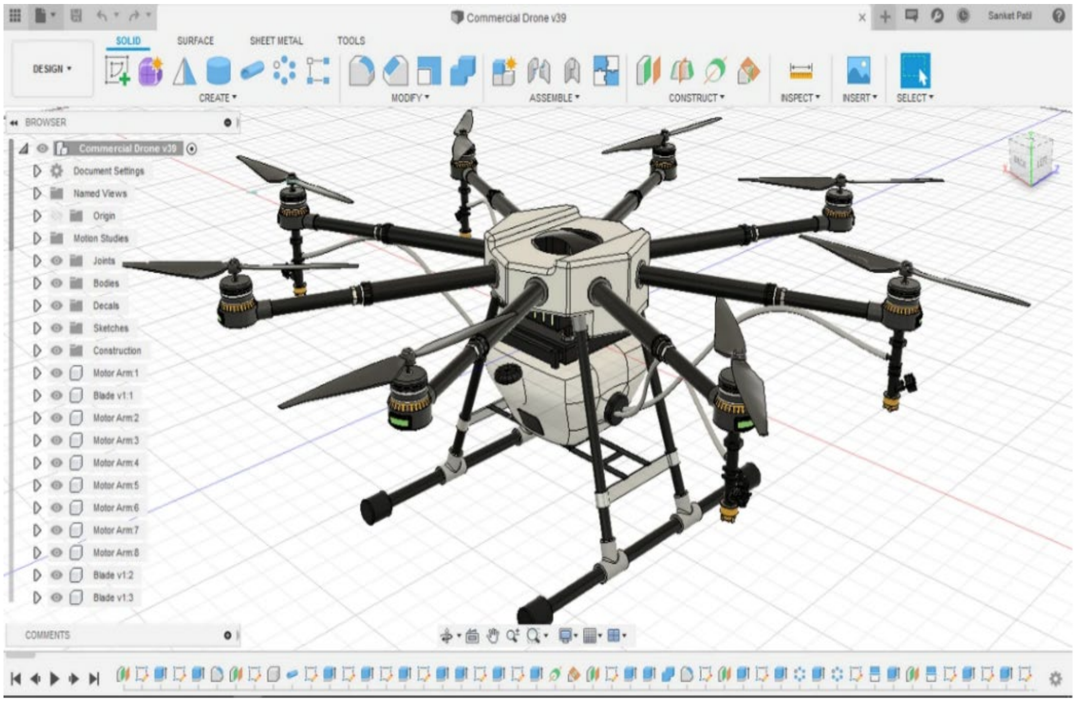
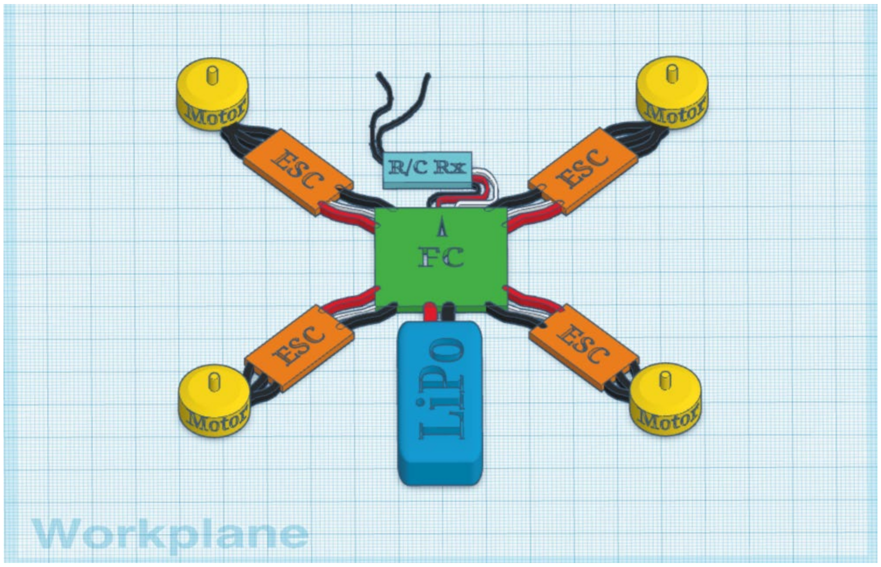


Figure 7
Student Drone Design According to Color Scheme in TinkerCAD



- **Raspberry Pi**: A microcontroller used in labs and assignments to teach fundamentals of embedded systems and electronic control.

There are several generations of Raspberry Pi available with different settings and learning environments. **Figure 8** visualizes a Raspberry Pi 4 Model B with a detailed overview of all ports and connectors.

Figure 8
Raspberry Pi 4 Model B. Source: Michael H. (Laserlicht)/Wikimedia Commons/CC BY-SA 4.0

The Raspberry Pi 400, a compact computer built into a keyboard, offers a versatile platform for learning coding, electronics, and robotics. When paired with a nano indoor drone (**Figure 10**), it creates a dynamic and engaging STEM teaching tool. **Figure 9** visualizes the respective hardware resources of the Raspberry Pi 400.

Figure 9
Raspberry Pi 400. Source: SimonWaldherr/Wikimedia Commons/CC BY-SA 4.0

Figure 10

Ryze Robotics Tello Edu variant. Source: SimonWaldherr/Wikimedia Commons/CC BY-SA 4.0

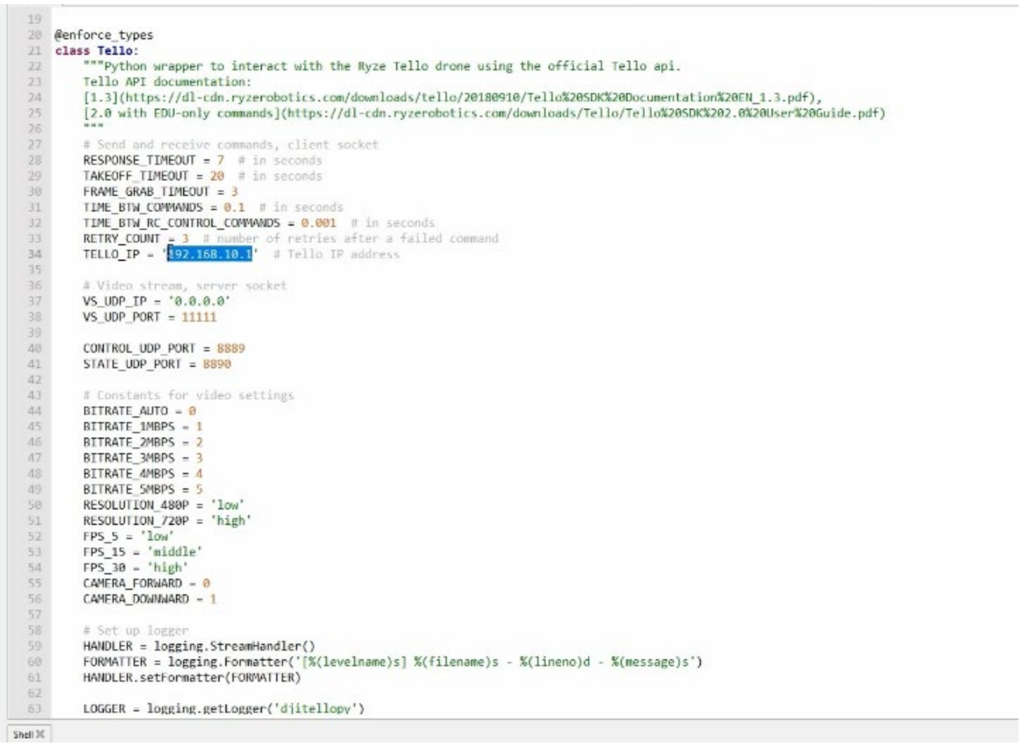
Figure 10 shows the Ryze Robotics Tello Edu variant, a typical nano-indoor drone for educational purposes, which we adopt in the underlying course example.

Connecting the nano drone and the Raspberry Pi 400 via data link, such as Bluetooth or Wi-Fi, enables the student to utilize programming interfaces to operate the aerial robotic vehicle. **Figure 11** shows an example of an instructor introducing the nano drone in an online class setting. Several assignments and activities introduce the general concept of the Raspberry Pi and the nano drones as platforms and concepts.

- **Python IDE**: Used to program drone behaviors and simulate flight control algorithms. Students learn to use script languages such as Python to control both the Raspberry Pi and the drone. They can write code to interface with GPIO pins on the Raspberry Pi for sensor integration and control external components. Additionally, students use Python or other programming languages to send commands to the drone, controlling its flight path, maneuvers, and interaction with external sensors.

Figure 11
Instructor demonstrating nano drones in Online Video

Figure 12
Python IDE for Programming Drones



```python

@enforce_types
class Tello:
    """Python wrapper to interact with the Ryze Tello drone using the official Tello api.
    Tello API documentation:
    [1.3](https://dl-cdn.ryzerobotics.com/downloads/tello/20180910/Tello%20SDK%20Documentation%20EN_1.3.pdf),
    [2.0 with EDU-only commands](https://dl-cdn.ryzerobotics.com/downloads/Tello/Tello%20SDK%202.0%20User%20Guide.pdf)
    """
    # Send and receive commands, client socket
    RESPONSE_TIMEOUT = 7  # in seconds
    TAKEOFF_TIMEOUT = 20  # in seconds
    FRAME_GRAB_TIMEOUT = 3
    TIME_BTW_COMMANDS = 0.1  # in seconds
    TIME_BTW_RC_CONTROL_COMMANDS = 0.001  # in seconds
    RETRY_COUNT = 3  # number of retries after a failed command
    TELLO_IP = '192.168.10.1'  # Tello IP address

    # Video stream, server socket
    VS_UDP_IP = '0.0.0.0'
    VS_UDP_PORT = 11111

    CONTROL_UDP_PORT = 8889
    STATE_UDP_PORT = 8890

    # Constants for video settings
    BITRATE_AUTO = 0
    BITRATE_1MBPS = 1
    BITRATE_2MBPS = 2
    BITRATE_3MBPS = 3
    BITRATE_4MBPS = 4
    BITRATE_5MBPS = 5
    RESOLUTION_480P = 'low'
    RESOLUTION_720P = 'high'
    FPS_5 = 'low'
    FPS_15 = 'middle'
    FPS_30 = 'high'
    CAMERA_FORWARD = 0
    CAMERA_DOWNWARD = 1

    # Set up logger
    HANDLER = logging.StreamHandler()
    FORMATTER = logging.Formatter('[%(levelname)s] %(filename)s - %(lineno)d - %(message)s')
    HANDLER.setFormatter(FORMATTER)

    LOGGER = logging.getLogger('djitellopy')
```

Figure 12 shows the course activities using the Python Integrated Development Environment (IDE) on the Raspberry Pi 400 connected to the nano drone.

These platforms collectively reinforce vertical skill development (e.g., propulsion analysis, CAD design) while embedding horizontal learning outcomes related to coding, logic, systems integration, and sustainability.

Pedagogical Strategies

The curriculum employs *project-based learning*, where students progress from drone design to programming and finally to performance simulation. Assignments are scaffolded to ensure students apply knowledge iteratively across technical and functional domains. For example:

- Students design an electric drone using CAD software and justify component selection based on propulsion requirements.
- They then simulate flight dynamics using SIMNET, evaluating trade-offs in power-to-weight ratio, motor efficiency, and energy use.
- In parallel, they use Python to create basic control algorithms and test the integration with embedded systems via Raspberry Pi platforms.

Instructors encourage reflection and cross-application of knowledge by incorporating guided discussions, peer review, and cross-functional team projects.

Mapping to the T-Shaped Model

This instructional model aligns directly with the T-shaped framework:

- **Vertical Axis (Depth)**: Students develop specialized expertise in electric propulsion systems, drone architecture, and simulation-based design.
- **Horizontal Axis (Breadth)**: Through programming, sustainability analysis, collaborative design, and ethical reflection, students build transferable competencies that support adaptability.

The program intentionally emphasizes *breadth as a lever for resilience*, giving students exposure to adjacent fields and fostering cognitive flexibility.

Results

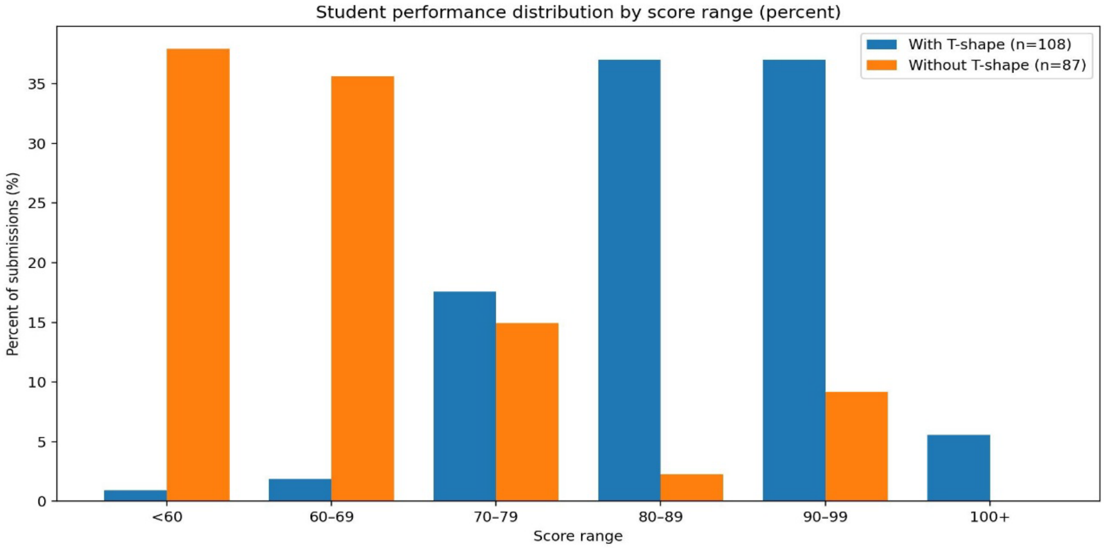
Implementation of the T-shape skills model in Robotics is associated with a pronounced upward shift in student performance relative to the section without the model. In the T-shape condition (n=108), scores cluster in the upper ranges: 79.6% of submissions fall between 80–99 (37.0% in 80–89 and 37.0% in 90–99), with an additional 5.6% achieving 100+. In contrast, without the T-shape model (n=87), performance is concentrated in the lower ranges: 73.5% of submissions score below 70 (37.9% under 60 and 35.6% in 60–69), and only 11.5% reach 80 or higher (2.3% in 80–89 and 9.2% in 90–99), with no submissions at 100+.

Figure 13 shows the distribution of scores by range (as percentages) for both conditions and highlights the shift away from low-score categories when the T-shape framework is implemented. In the T-shape section, very few submissions fall below 70 (2.8% total), whereas the non–T-shape section is dominated by scores below 70 (73.5% total). Conversely, high scores (≥80) constitute the majority of submissions with the T-shape model (79.6%) but represent a small minority without it (11.5%). The midrange (70–79) is relatively similar across conditions (17.6% with T-shape vs. 14.9% without), suggesting the primary difference lies in the reduction of low performance and the increased concentration of high performance rather than a modest shift around the middle.

Figure 13 indicates that integrating the T-shape skills framework in *Robotics* corresponds to substantially stronger overall performance, characterized by a marked decrease in low-scoring submissions and a pronounced increase in submissions scoring 80 and above.

Figure 13

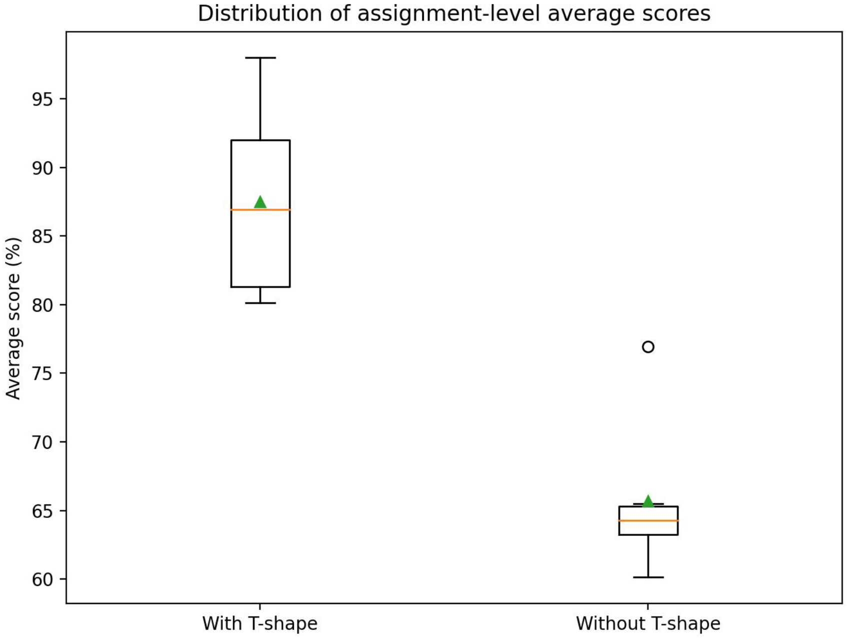
Distribution of Student Submission Scores by Score Range (Percent)



The boxplot in **Figure 14** compares the distribution of assignment-level average scores between Robotics sections taught with and without the T-shape skills model. It shows a clear separation between the two conditions: the median average score is substantially higher in the T-shape section, and the entire interquartile range (middle 50% of values) is positioned well above the non–T-shape section. In addition, the T-shape condition shows relatively tight clustering of averages in the high-performance range, indicating more consistently strong outcomes across assignments. By contrast, the non–T-shape section's averages cluster in a much lower range with a narrower spread around a lower median, with one higher-value point appearing as an outlier. Overall, the boxplot visually reinforces that implementing the T-shape model is associated with higher typical performance and a strong upward shift in assignment averages compared to the section without the model.

Figure 14

Boxplot of Assignment-Level Average Scores (%) for Robotics Sections Taught with the T-Shape Skills Model Versus without the Model.



Discussion

The implementation of the T-shaped skills model in engineering education presents several key benefits, particularly in preparing students for an unpredictable and rapidly evolving technological landscape. As industries face continuous disruption from artificial intelligence, electrification, automation, and environmental pressures, engineers must be equipped not only with specialized expertise but also with the agility to transfer their skills across new and emerging domains. The T-shaped framework directly supports this objective by promoting both depth and breadth in student learning.

This model enhances resilience to skill disruption by preparing students to operate across boundaries. Deep disciplinary expertise provides the confidence and proficiency to perform in technically demanding roles, while horizontal competencies, such as programming, sustainability awareness, systems thinking, and communication, enable students to connect with adjacent fields, integrate knowledge, and adapt when their core technical skills evolve or become less central. In this sense, resilience is not just the ability to withstand change, but the capacity to reorient and thrive within it. Students trained in T-shaped programs are more likely to pivot into related fields, pursue interdisciplinary roles, or acquire new technologies without starting from scratch.

In this case study, resilience was not measured using a standardized instrument but was inferred from observable indicators of interdisciplinary competence development. These indicators included students' ability to transfer domain knowledge to new applications, integrate mechanical and computational concepts within a single project, adapt designs in response to constraints, and successfully complete tasks requiring coordination across multiple technical domains. Such behaviors are consistent with constructs described in the literature as adaptive expertise, cognitive flexibility, and career resilience.

Because the study focuses on curricular implementation rather than outcome evaluation, no formal scale of long-term adaptability was administered. This represents an important limitation. Future research could employ validated instruments, such as adaptive expertise scales, engineering identity measures, career resilience surveys, or performance-based longitudinal assessments, to quantify the impact of T-shaped curricula on graduates' ability to navigate technological change over time.

Interdisciplinary and online learning environments played a critical role in enabling this transformation. Online platforms supported a modular course architecture, allowing both horizontal and vertical competencies to be embedded without overwhelming any single course. This flexibility allowed students to experience the T-shape architecture through scaffolded progression, building deep knowledge in propulsion and simulation while incrementally applying coding, sustainability, or teamwork skills in related modules. Online modalities also supported consistent use of shared platforms like SIMNET and TinkerCAD across course sections, improving scalability and alignment of learning outcomes.

Drone-based instruction and electric propulsion concepts served as particularly effective anchors for the T-shaped framework. Drones integrate mechanical, electrical, and computational elements, making them ideal for teaching across domains. Through a single platform, students can engage in hands-on tasks related to propulsion modeling, circuit integration, Python programming, and system simulation. This kind of cross-domain learning supports both axes of the T: students deepen their understanding of propulsion and design while applying it through interdisciplinary lenses. The use of simulation tools provided further benefits, allowing students to test, refine, and optimize systems under realistic conditions without access to physical labs, an advantage especially important in online and resource-constrained contexts.

The Robotics results strengthen the case that a T-shaped skills model supports both higher-quality work and more consistent student outcomes. Observing the distribution of submission scores by range, implementation of the model corresponds to a clear shift away from lower score bands and toward higher performance ranges, suggesting that students are not merely improving marginally but are more reliably meeting the expectations of integrative, applied Robotics tasks. The boxplot tells the same story at the aggregate level: typical performance is centered higher under the T-shaped approach, and the overall distribution indicates a stronger "floor" with fewer indications of widespread struggle. Taken together, these visual patterns align with the intended mechanism of the framework; students build technical depth while also developing cross-cutting competencies (e.g., systems thinking, communication, and integration across tools and concepts), which are especially critical in robotics, where success depends on executing multi-step problem solving, troubleshooting, and connecting knowledge across domains.

Despite these advantages, the T-shaped framework presents implementation challenges. Balancing technical depth and interdisciplinary breadth within existing program constraints, such as credit limits, faculty expertise, and accreditation guidelines, can be difficult. Institutions may face logistical barriers in sustaining interdisciplinary offerings or coordinating faculty across departments. Another significant challenge is assessment: while vertical knowledge is traditionally evaluated through exams and design projects, the assessment of horizontal competencies like systems thinking or sustainability awareness is more nuanced and often subjective. Without structured rubrics or integrative capstone experiences, these competencies risk being underdeveloped or undervalued.

To improve the framework's application, one modification would be to take a *distributed curricular approach*, where not every course aims to address the full T-shape. Instead, core technical courses focus on vertical depth, while electives, interdisciplinary modules, and capstone projects are designed to explicitly develop horizontal competencies. Institutions can also support faculty in designing interdisciplinary projects, case studies, and assessment methods that align with both vertical and horizontal learning goals. Clear mapping of learning outcomes to the T-shaped structure can ensure that students experience a cohesive developmental arc rather than isolated learning moments.

Although this study focuses on drone-based instruction as an integrative platform, the T-shaped competency framework is not tied to any single technology domain. The model can be extended to other emerging fields that inherently require cross-disciplinary integration. For example, space technologies combine propulsion, structures, communications, thermal systems, orbital mechanics, and software autonomy, making them ideal environments for cultivating both deep specialization and broad systems understanding. Similarly, autonomous vehicle platforms integrate mechanical design, sensing technologies, artificial intelligence, control systems, cybersecurity, and human–machine interaction. In both cases, students must navigate complex interactions among physical hardware, computational systems, and societal considerations such as safety, regulation, and sustainability.

Institutional barriers such as credit-hour limitations and departmental silos can be mitigated through modular curriculum structures that embed interdisciplinary themes across existing courses rather than creating entirely new programs. Shared laboratories, cross-listed courses, and project-based capstone experiences can serve as focal points for horizontal skill development while preserving disciplinary depth. Online and hybrid delivery formats further enable collaboration across departments and institutions, reducing logistical constraints. By leveraging such strategies, the T-shaped model can support scalable curricular transformation across diverse engineering domains beyond uncrewed systems.

Ultimately, the T-shaped model offers a strategic and adaptable approach to building resilience in engineering education. The case study demonstrates that when students are engaged with interdisciplinary platforms like drones, challenged to connect knowledge across technical and social domains, and supported through flexible online delivery, they not only build expertise but also learn to adapt, collaborate, and grow in response to change.

Conclusion

This study explored how the T-shaped competency model can be implemented in engineering education to build student resilience and curricular agility in response to rapid technological change. By integrating electric propulsion and drone-based instruction into an online undergraduate curriculum, we demonstrated how a carefully structured combination of vertical expertise and horizontal breadth can support students in developing both deep technical capabilities and cross-disciplinary flexibility. This dual emphasis equips learners not only to excel in their chosen fields but also to adapt to new tools, roles, and industries as technology evolves.

The T-shaped model effectively addresses the challenges of skill disruption by cultivating transferable knowledge and fostering an adaptive mindset. In our case study, students demonstrated the ability to apply their disciplinary understanding in new interdisciplinary contexts, engage with multiple systems, and approach problems holistically, hallmarks of resilience in a dynamic workforce. The online learning environment, combined with simulation and hands-on tools like SIMNET, TinkerCAD, and Raspberry Pi, provided the necessary infrastructure for modular and scalable curriculum design that supported this development.

However, broader implementation of the T-shaped framework will require strategic adjustments. Program structures must allocate space for both depth and breadth without diluting either. Faculty development, interdisciplinary collaboration, and thoughtful assessment strategies will be essential in ensuring that horizontal competencies are not treated as add-ons but as integral components of the learning experience.

Looking ahead, future research should explore how T-shaped learning models influence graduates' long-term career outcomes, including adaptability, cross-disciplinary collaboration, and mobility across emerging industries. Longitudinal studies tracking alumni from T-shaped programs could yield valuable insights into how well these competencies translate into workforce success over time. Another future direction could focus on more formal *assessment tools and rubrics* to measure horizontal competencies such as systems thinking, sustainability integration, and ethical reasoning. There is also a need for *longitudinal studies* that track graduates of T-shaped programs to assess the long-term impact on adaptability, career mobility, and innovation capacity. Additionally, opportunities exist to *expand this model to other emerging domains*, such as AI-integrated systems, space technologies, and autonomous vehicle platforms, where deep knowledge must coexist with broad technical and societal awareness.

Developing robust assessment frameworks for T-shaped learning remains an important research need. Longitudinal studies that combine validated resilience metrics, performance-based assessments, and career outcome data would provide stronger evidence of how interdisciplinary education influences graduates' adaptability in rapidly evolving technological fields.

As engineering education continues to evolve, the T-shaped framework offers a robust, learner-centered model that can respond to both the technical demands of the future and the human skills required to navigate it. By embedding this framework into interdisciplinary, flexible, and experiential learning environments, educators can help cultivate a generation of engineers who are not only specialized but also resilient, reflective, and ready.

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