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Integrating R&D space projects into aerospace engineering master's education at MCAST

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Abstract

Purpose – This research study evaluates the efficacy of research-based learning (RBL) in bridging the persistent epistemological and practical gap between theoretical vocational education and industrial research and development (R&D) within the Level 7 aerospace curriculum at the Malta College of Arts, Science and Technology (MCAST). As the global aerospace sector undergoes a structural transition toward Industry 4.0 and the "New Space" commercial paradigm, conventional transmissive instructional models prove insufficient for equipping postgraduate students with the multidisciplinary, adaptive competencies demanded by the industry.

Design/methodology/approach – This article systematically examines the pedagogical integration of active, high-stakes space missions, specifically the Advanced Spacecraft Technology for Repairing of Broken External Armor using cold-welding adhesion Treatment (ASTROBEAT) and the Smart Ballistic Optimization for Repairing of Aerospace Exostructures using 3D-printed Kevlar (SBORAEK), into the MCAST Master of Science in Aerospace Engineering. The study contextualizes this educational framework within the strategic expansion of Malta as an emerging space nation, analyzing the structural imperatives dictated by the Malta Space Act, the European Space Agency's Plan for European Cooperating States (ESA PECS) and the impending harmonization driven by the proposed EU Space Act.

Findings – Utilizing a systematic desk-based qualitative methodology, the research synthesizes literature on experiential learning, andragogy, transdisciplinary STEAM integration and digital quality assurance. The findings suggest that involving students in orbital experiments and hypervelocity impact research supports the development of EQF Level 7 competencies. The analysis provides a framework for institutions seeking to transform student learning from passive theoretical absorption into active contributions to the international space sector, ensuring rigorous alignment with contemporary industrial, legal and regulatory standards.

Research limitations/implications – While this study provides a comprehensive framework for integrating RBL into vocational aerospace education, several limitations must be acknowledged. First, the analysis relies predominantly on desk-based qualitative literature review and curriculum evaluation rather than longitudinal quantitative data. Consequently, the direct long-term impact of these initiatives on graduate employability and career trajectory remains to be empirically validated. Second, the study is situated within the specific institutional context of MCAST and the Maltese aerospace sector; therefore, the findings may not be uniformly generalizable to larger institutions or nations with fundamentally different regulatory and industrial landscapes.

Practical implications – This study provides a practical framework for higher education institutions to transition students from theoretical learning to active aerospace R&D. It demonstrates how embedding real space missions into curricula equips graduates with industry-ready competencies, systems engineering skills and regulatory awareness of frameworks like the EU Space Act and ESA standards. Practically, this model requires institutions to adapt their assessment strategies and secure sustained investments in laboratory infrastructure and international collaborations. Ultimately, aligning vocational education with high-stakes industrial research drives workforce development and builds innovation capacity within emerging space nations.

Social implications – By integrating high-stakes aerospace research and transdisciplinary STEAM activities into vocational education, this framework democratizes access to the international space sector for students in

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emerging space nations like Malta. The inclusion of public-facing initiatives, such as broadcasting space-inspired musical compositions from the International Space Station, translates complex astronautical concepts into accessible cultural experiences. Consequently, educational institutions within smaller member states can actively drive regional innovation ecosystems, elevate national technological visibility and cultivate a skilled workforce capable of contributing to global orbital sustainability and the broader European space economy.

Originality/value – This study provides original value by examining the rare integration of active, high-stakes space missions, such as ISS orbital experiments and hypervelocity impact tests, into a postgraduate vocational aerospace curriculum. While existing literature frequently focuses on simulated project-based learning, this research uniquely evaluates live RBL within the specific context of an emerging space nation, Malta. It provides a valuable, scalable framework for institutions to successfully bridge the gap between theoretical instruction and industrial R&D. Furthermore, it uniquely synthesizes pedagogical theories with contemporary regulatory paradigms, including the ESA PECS framework and the proposed EU Space Act.

Keywords Aerospace engineering, Vocational education, Research-based learning, ESA PECS, STEAM integration

Paper type Research article

1. Introduction

The aerospace sector has changed rapidly in recent years due to the growth of commercial space activities, large satellite constellations, reusable launch vehicles and advances in manufacturing technologies (Cedefop and ReferNet Malta, 2019). Within this highly dynamic environment, the profile of the aerospace engineer is fundamentally changing. Contemporary professionals can no longer operate exclusively within narrow technical domains; instead, they are required to navigate complex multidisciplinary ecosystems that combine systems engineering, high-dimensional data analysis, materials science, strict regulatory compliance, environmental sustainability assessment and applied research methodologies (Freire, 2000). Consequently, higher vocational education institutions are challenged to move decisively beyond traditional transmissive instructional approaches (Falzon *et al.*, 2011; Knowles, 1980). The establishment of educational models capable of preparing graduates for uncertain and research-intensive industrial environments has become an essential requirement. Postgraduate aerospace education cannot remain detached from active industrial practice; curricula must expose learners to authentic engineering workflows, interdisciplinary collaboration, technical documentation standards, risk management procedures and the stringent operational constraints associated with space missions and experimental microgravity research (Levy and Petrulis, 2012; Loeng, 2020).

Within this evolving geopolitical and technological context, Malta has progressively positioned itself as an emerging participant in the European aerospace and space ecosystem (Barilaro *et al.*, 2022). Supported by the Malta National Space Strategy, the Malta Space Act (Government of Malta, 2025) and increasing cooperation with the European Space Agency (ESA) through the Plan for European Cooperating States (PECS) framework (European Space Agency, 2023), the jurisdiction has begun to establish the institutional foundations required to support local research, technological development and international collaboration.

The Malta College of Arts, Science and Technology (MCAST) plays a central role in this transition through the launch of its Aerospace Programme in 2020 and the subsequent Master of Science in Aerospace Engineering in 2021 (Barilaro, 2022). The program was intentionally designed as a flexible, blended-learning vocational framework capable of integrating industrial practice with applied research activity.

A persistent pedagogical challenge, however, remains evident across the sector. Traditional engineering education frequently privileges the transmission of theoretical knowledge through highly structured lectures, standardized laboratory exercises and predefined engineering problems. While these methods possess value for establishing technical foundations, they consistently fail to fully prepare postgraduate learners for the ambiguity, complexity and interdisciplinary decision-making demanded by contemporary aerospace research and development (R&D) (Healey and Jenkins, 2009; Laksono and Kuncahyono, 2026). This limitation becomes particularly acute in highly specialized domains such as orbital experimentation, hypervelocity impact analysis, space debris mitigation and advanced materials testing, where outcomes are inherently uncertain and engineering judgment plays a central role.

This study evaluates research-based learning (RBL) (Healey and Jenkins, 2009; Levy and Petrulis, 2012) as an optimal pedagogical strategy capable of bridging the persistent divide between postgraduate vocational education and industrial aerospace research. The research examines the active integration of two flagship MCAST initiatives, ASTROBEAT and SBORAEK, into the MSc curriculum. These projects expose learners to genuine aerospace engineering challenges associated with cold-welding adhesion phenomena, ballistic structural impacts, additive manufacturing and spaceflight systems validation. Rather than functioning as isolated academic exercises, these projects form part of active R&D activities connected to real technical objectives, external funding collaborations and international space-sector dynamics.

The study also addresses the broader educational and regulatory implications of embedding high-stakes R&D within vocational curricula. Specific attention is directed to the relationship between applied research, EQF Level 7 competency acquisition, Science, Technology, Engineering, Arts and Mathematics (STEAM) integration (Carter *et al.*, 2021; Segarra *et al.*, 2018), quality assurance (QA) in blended learning environments (Martínez-Gómez *et al.*, 2022; Toth, 2008) and the increasing influence of European regulatory frameworks, prominently the proposed EU Space Act (European Commission, 2025). Through a qualitative desk-based review of pedagogical, industrial and policy literature, this research constructs a structured, scalable framework for integrating live aerospace research into postgraduate education while maintaining academic rigor, industrial relevance and institutional sustainability.

Guided by the study's core objectives, the research framework is driven by three interconnected inquiries. Primarily, it investigates the mechanisms through which RBL can be effectively integrated into postgraduate aerospace engineering education within a higher vocational context. Subsequently, the study assesses the specific educational benefits and competency-development opportunities generated by embedding live aerospace R&D projects into an MSc curriculum. To ground these inquiries in practical application, the research finally evaluates how the ASTROBEAT and SBORAEK missions concretely facilitate EQF Level 7 competency acquisition and support workforce development within the ecosystem of an emerging space nation.

2. The Maltese aerospace sector and the European regulatory framework

The pedagogical requirements of postgraduate aerospace education are closely influenced by the industrial and regulatory environments in which graduates are expected to operate. This section contextualizes the MCAST curriculum within the structural evolution of the Maltese aerospace sector, tracing its expansion from traditional aviation maintenance to advanced space technology (Barilaro, 2022). Furthermore, it outlines the multi-layered legal and institutional frameworks, specifically the impending EU Space Act (European Commission, 2025), the Malta Space Act (Government of Malta, 2025) and the ESA PECS agreement (European Space Agency, 2023), that govern contemporary orbital activities and dictate the operational parameters future engineers must navigate.

2.1 Evolution of the local aerospace industry

The Maltese aerospace sector has historically been anchored by a robust Maintenance, Repair and Overhaul (MRO) industry, with facilities establishing the island as a critical node in European aviation logistics. Adapting to global market shifts, Malta has strategically diversified its portfolio to encompass upstream and downstream space technologies. Previous analyses of the sector suggest favorable conditions for this expansion: strengths include a qualified, work-based learning (WBL) trained workforce and deep-rooted relationships with major aviation entities. Opportunities are expanding through extensive foreign direct investments and the localized establishment of R&D facilities (Barilaro, 2022). One identified limitation, namely a lack of deep-space hardware design experience, is being systematically addressed through international research consortiums, notably MCAST's sustained collaboration with the Center of Studies and Activities for Space (CISAS) at the University of Padova (Barilaro *et al.*, 2022).

The development of specialized R&D infrastructure serves as a primary driver for this sectoral evolution. As detailed by Barilaro *et al.* (2022), institutional efforts have supported the development of Malta's first hypervelocity impact testing facility. From an educational perspective, this infrastructure provides opportunities for students to engage with experimental testing activities relevant to both academic and industrial research.

2.2 The EU space act and national legal frameworks

The pedagogical requirements of modern aerospace engineering cannot be decoupled from the prevailing and impending regulatory environment. The proposed Regulation of the European Parliament and of the Council on the safety, resilience and sustainability of space activities in the Union (commonly referred to as the EU Space Act) (European Commission, 2025) may represent a significant development in the governance of space operations within the European Union. The proposal explicitly addresses the fragmented regulatory landscape resulting from uncoordinated national space laws, establishing a cohesive internal market for space services (European Commission, 2025).

For aerospace engineering master's students, the proposed legislation (European Commission, 2025) provides insight into the regulatory requirements that may increasingly shape future professional practice. The legislation introduces targeted harmonization across three pillars: Safety, Resilience and Environmental Sustainability. Regarding safety, the Act mandates stringent space debris mitigation plans, requiring launch vehicles and spacecraft to minimize debris generation, ensure trackability and implement collision avoidance (CA) protocols. From a resilience perspective, it establishes a bespoke risk management baseline, obligating operators to conduct cyber and physical risk assessments throughout the space mission lifecycle, aligning with NIS 2 and CER Directives (European Commission, 2025). Environmentally, the Act requires the calculation of the environmental footprint of space activities utilizing standardized Life Cycle Assessment (LCA) methodologies.

At the national level, the Malta Space Act (Government of Malta, 2025) operationalizes these overarching principles within the jurisdiction, providing the necessary legal certainty for space operators. Integrating these regulatory considerations into the MCAST MSc curriculum may help ensure that RBL projects like ASTROBEAT are not only technically robust but fully compliant with future tracking, passivation and debris mitigation standards (Government of Malta, 2025).

2.3 The ESA PECS framework

Malta's integration into the broader European space ecosystem is formalized via its strategic cooperation with the European Space Agency (ESA). This relationship follows a structured accession trajectory: transitioning from a general Cooperation Agreement to a Plan for European Cooperating States (PECS) (European Space Agency, 2023), with the ultimate objective of achieving Associate Member status.

The PECS framework (European Space Agency, 2023) was established to support the development of national space capabilities across industry and academia. It enables ESA and the Cooperating State to execute concrete activities, preparing the nation for full integration into ESA's mandatory and optional programs. For MCAST, PECS provides an indispensable funding, validation and capacity-building mechanism (European Space Agency, 2023). It heavily subsidizes the technological readiness levels (TRLs) of local projects and facilitates the spin-out of academic research into industrial applications. By participating in restricted open calls under PECS, students and faculty gain direct exposure to ESA's rigorous procurement processes, the European Cooperation for Space Standardization (ECSS) frameworks and international supply chain dynamics (European Space Agency, 2023).

Collectively, these industrial, legal and institutional developments establish the context within which postgraduate aerospace education is delivered in Malta. As the national aerospace ecosystem continues to evolve, educational programs must increasingly prepare graduates not only with technical competencies but also with an understanding of regulatory compliance, systems engineering practices and international collaboration frameworks. These contextual factors provide the rationale for integrating authentic research and development activities within the MCAST MSc curriculum.

3. Research design and methodology

This study adopts a qualitative desk-based systematic literature review and curriculum analysis methodology to examine the integration of active aerospace RBL R&D projects within postgraduate vocational education. The methodological approach was selected because the research objective transcends measuring isolated educational variables; it seeks to synthesize pedagogical theory, institutional practice, aerospace industry requirements and European regulatory developments within a singular analytical framework rather than to measure causal relationships or evaluate student performance quantitatively. The study operates strictly within a constructivist paradigm, recognizing that educational processes in advanced engineering contexts are profoundly shaped by institutional culture, industrial expectations, technological infrastructure and learner interaction (Creswell and Creswell, 2018; Schutt, 2012).

Literature searching was conducted between January and April 2026 using Scopus, IEEE Xplore, ScienceDirect, SpringerLink and Google Scholar. Searches combined keywords related to RBL, vocational education, aerospace engineering education, Industry 4.0, STEAM integration, orbital sustainability, hypervelocity impacts and digital QA.

Sources were selected based on their relevance to the objectives of the study. Priority was given to peer-reviewed publications addressing engineering education, adult learning, vocational higher education, aerospace training and interdisciplinary learning. Additional policy and institutional documents were included where they provided direct contextual relevance to the Maltese aerospace sector and the regulatory environment in which the MCAST program operates. Source selection was governed by four primary criteria: relevance to postgraduate vocational and engineering education; alignment with pedagogical theories including RBL, STEAM and andragogy; applicability to aerospace research, workforce development and sector-specific regulatory frameworks; and, crucially, demonstrated methodological rigor and academic quality.

Sources were excluded when they focused exclusively on technical aerospace topics without educational relevance, lacked sufficient methodological transparency or did not contribute directly to the conceptual framework of the study.

In addition to traditional academic literature, the review intentionally incorporated policy-oriented and institutional documentation. These sources encompassed Malta's National Space Strategy, the Malta Space Act, ESA PECS documentation, the proposed EU Space Act, internal MCAST QA procedures and the comprehensive technical and managerial documentation connected to the ASTROBEAT and SBORAEK projects. The integration of grey literature is essential, as vocational aerospace education is heavily dictated by industrial frameworks, compliance structures and institutional governance mechanisms not consistently represented within conventional academic journals (Barbieri *et al.*, 2025; Foucault, 1972).

Following source selection, documents were reviewed iteratively according to recurring concepts relevant to the research objectives. The analytical process followed the principles of thematic analysis as described by Braun and Clarke (2022). Sources were systematically reviewed, clustered and comparatively analyzed to identify recurring epistemological tensions. The methodology also explicitly acknowledges researcher positionality (Goundar, 2025). The research was conducted from the perspective of the main author as a Senior Lecturer in Aerospace Engineering at MCAST and the Principal Investigator on the ASTROBEAT and

SBORAEK projects. This insider perspective provides detailed knowledge of the technical, educational and operational processes associated with the projects under investigation. To safeguard academic rigor and confirmability, continuous epistemic reflexivity was applied, critically evaluating interpretive choices to mitigate potential confirmation bias.

4. Literature review and theoretical framework

The transition toward Industry 4.0 within the global aerospace sector has prompted a critical re-evaluation of the educational models utilized within vocational education and training (VET). The paradigm shift, marked by the integration of cyber-physical systems, advanced additive manufacturing and complex orbital logistics, prompts a necessary pedagogical evolution. As the technical demands of the aerospace industry increase in complexity, a growing body of educational scholarship suggests that traditional, transmissive instructional methods may be insufficient on their own for cultivating the adaptive, problem-solving competencies required of modern engineers (Cedefop and ReferNet Malta, 2019).

Within the specific institutional context of MCAST and its Level 7 MSc in Aerospace Engineering, this pedagogical transition is a strategic priority. As Malta seeks to develop local competencies capable of actively participating in the international Space economy, higher vocational institutions are tasked with bridging the persistent gap between theoretical instruction and applied industrial research. This literature review systematically examines contemporary scholarship concerning advanced VET, RBL, the integration of STEAM and the mechanisms of QA in digital education, establishing a robust theoretical framework for the integration of space R&D projects into the curriculum.

4.1 Philosophical foundations of applied vocational education

The integration of RBL into a highly specialized vocational aerospace curriculum can be informed by a philosophical foundation that addresses the relationship between theoretical instruction and practical application. A primary reference point for this integration is John Dewey's seminal conceptualization of experiential learning (Dewey, 1938). Dewey argued that education should not be conceived merely as a preparatory stage for future employment or isolated academic achievement; rather, it involves a continuous, lived process of resolving genuine problems encountered within the learner's immediate experience (Dewey, 1938).

In the context of aerospace VET, Dewey's pragmatic approach challenges traditional, transmissive instructional models heavily reliant on lecture formats and the rote memorization of technical data. Such methods rely on what Freire (2000) termed the "banking concept" of education (Freire, 2000). While transmissive methods efficiently deliver codified foundational knowledge, experiential frameworks suggest they may provide limited opportunities for learners to address novel and ill-structured engineering problems. Dewey's theory proposes that when learners face authentic, unstructured challenges, they are compelled to engage in active hypothesis testing, facilitating deeper cognitive acquisition (Dewey, 1938).

Furthermore, experiential learning requires supplementation with theories of critical reflexivity. Paulo Freire's critical pedagogy, particularly his concept of conscientization, developing a critical awareness of one's professional reality, is essential for Level 7 engineering education (Freire, 2000). Aerospace engineering demands strict adherence to safety protocols, yet equally requires practitioners capable of critically analyzing system failures, adapting to unforeseen challenges in extreme environments such as microgravity, and questioning established procedures. Integrating unresolved research projects into the curriculum may provide opportunities for the development of such critical agency. This emphasis aligns with Falzon's "3R model" of Reflection, Reflexivity and Resolved action (Falzon *et al.*, 2011). In projects like ASTROBEAT, the resolved action transcends academic submission, materializing as practical aerospace experimentation and the physical design of hardware for orbital deployment.

4.2 The evolution of educational delivery: from pedagogy to andragogy

Designing curricula for postgraduate VET learners requires theoretical alignment with andragogy, the facilitation of adult learning. Knowles (1980) identified adult learners as self-directed individuals drawing upon vast reservoirs of accumulated experience, motivated by the immediate relevance of the material to their professional roles (Knowles, 1980). Master's level aerospace students at MCAST frequently fit this profile, operating in a complex liminal space as both academic learners and active industrial WBL practitioners within the expanding MRO sector.

An andragogical framework democratizes the learning environment, repositioning the educator as a facilitator. By engaging learners in identifying problems and evaluating outcomes, the curriculum bridges the necessary tension between the strict regulatory frameworks enforced by aviation authorities and the exploratory, unconstrained demands of aerospace R&D (Knowles, 1980; Loeng, 2020). The literature notes that transitioning to self-directed learning models requires careful facilitation, as learners accustomed to highly structured environments may initially experience cognitive friction (Loeng, 2020). Consequently, ongoing mentorship and a gradual release of responsibility are paramount for fostering the resilience and adaptability required to succeed in the evolving aerospace sector.

4.3 Pedagogical innovations: research-based learning and high-stakes R&D

RBL serves as the primary instructional vehicle for operationalizing these philosophical principles. RBL positions students as active participants in inquiry processes that mirror professional disciplinary research (Levy and Petrulis, 2012). Unlike project-based learning, which typically utilizes predefined projects with known outcomes (Laksono and Kuncahyono, 2026), RBL demands that students interrogate evidence regarding genuinely unsolved phenomena. Engaging with authentic constraints, such as developing spaceflight hardware aligned with uncompromising ECSS engineering standards, cultivates a "reflective practitioner" mindset (Schön, 1983).

Analyzed through Bloom's Taxonomy (Bloom, 1956), traditional engineering education frequently stagnates at lower cognitive tiers (Remembering, Understanding, Applying). Engaging with the complex datasets generated by real-world aerospace projects forces students to operate within the apex domains: Evaluating (justifying design choices under conflicting constraints) and Creating (formulating novel solutions for extreme environments). Research on inquiry-based environments notes that students may experience heightened workload, ambiguity and anxiety when confronted with ill-structured tasks and open-ended criteria, especially without adequate scaffolding (Levy and Petrulis, 2012). Therefore, structured mentorship and clear communication of expectations are vital to mitigate cognitive risks while maximizing pedagogical benefits (Healey and Jenkins, 2009; Hestad *et al.*, 2023).

4.4 The STEAM paradigm: transdisciplinarity in extreme environments

Addressing the complex cognitive demands of modern aerospace engineering requires broadening the STEM epistemology to embrace transdisciplinary perspectives, formally integrating the Arts to form STEAM (Carter *et al.*, 2021; Segarra *et al.*, 2018). Robust transdisciplinary integration minimizes disciplinary boundaries, supporting the holistic understandings of complex systems and enhancing the divergent thinking necessary for nonlinear innovation in high-risk environments (Segarra *et al.*, 2018).

This epistemological shift is institutionalized through initiatives bridging strict technical space technology with creative arts. As noted by Lisi (2024), profound linguistic and methodological frictions can occur when art and engineering intersect (Lisi, 2024). Overcoming these barriers requires deliberate pedagogical scaffolding (Kashaka, 2024). In highly technical fields, methodologies like data sonification, the algorithmic translation of high-dimensional datasets into structured sound, offer alternative cognitive tools for interpreting chaotic data, such as acoustic emission frequencies from hypervelocity impacts (Carter *et al.*, 2021). Integrating sonic arts with aerospace technology provides a method for transcending disciplinary communication barriers (Otheguy *et al.*, 2015). While STEAM approaches are frequently associated with primary and secondary education, recent scholarship suggests that transdisciplinary perspectives may also contribute to higher education by enhancing creativity, communication skills and systems thinking. These competencies are increasingly relevant in aerospace engineering, where technical challenges often intersect with human, social and operational considerations.

4.5 Quality assurance and digital pedagogy in blended VET

Since the MCAST MSc program is delivered through a blended-learning model, the successful implementation of RBL also depends on effective digital learning environments and associated QA mechanisms.

The implementation of RBL and STEAM is heavily reliant on digital delivery mechanisms. Modern e-learning frameworks emphasize active engagement and multimodal content delivery over the static digitization of traditional transmissive lectures (Prensky, 2001; Tapscott, 2010). Integrating interactive simulations enables learners to visualize orbital mechanics and material behaviors that are otherwise inaccessible (Fleming, 2014; Kolb, 1984).

Transitioning to complex digital pedagogy presents significant challenges regarding QA (OECD, 2009). Traditional micro-level internal quality assurance processes, heavily reliant on qualitative peer observation, may suffer from observer bias when applied to highly technical, asynchronous environments. The literature advocates for supplementing these interpretative judgments with data-driven, quantitative QA methodologies, such as web-mining techniques to objectively analyze learner interactions (Martínez-Gómez *et al.*, 2022; Toth, 2008). Tracking navigation paths and engagement with complex simulations provides a comprehensive, objective assessment of e-learning efficacy in imparting critical engineering competencies.

4.6 Research gap and conceptual framework

Although substantial literature exists on experiential learning, andragogy, inquiry-based learning and STEAM education, comparatively limited attention has been devoted to the integration of active aerospace R&D projects within postgraduate vocational engineering programs. Furthermore, little research has examined such approaches within the context of emerging space nations and small-state innovation ecosystems.

This study addresses this gap by examining how live aerospace research projects can be embedded within a Level 7 vocational curriculum while simultaneously supporting competency development, regulatory awareness and industry engagement. The theoretical perspectives discussed above provide the conceptual framework through which the ASTROBEAT and SBORAEK initiatives are analyzed.

5. Curriculum design: the MCAST MSc in aerospace engineering

The Master of Science in Aerospace Engineering at MCAST was launched in October 2021 as a part-time, flexible and blended-learning program designed to address the highly specialized needs of the evolving aerospace sector. Developed following extensive stakeholder analyses with local MRO entities and informed by core values from leading European institutions, the program targets undergraduates and active professionals seeking to upskill in the expanding space and aviation business sectors (Barilaro, 2022; Cohen *et al.*, 2007).

The curriculum is structured across three academic years (120 ECTS), offering distinct exit points (Postgraduate Certificate and Postgraduate Diploma). The core instructional units in the first year cover Aerospace Structures, Aircraft Propulsion, Measurements for Aerospace, Aviation Maintenance Management and Aerodynamics. In the second year, students pursue specialization in one of three focused areas: Structures and Measurements for Aerospace, Aerodynamics or Space Technologies. The Space Technologies pathway specifically mandates advanced units on Space Propulsion, Astrodynamics, Thermal Control and Spacecraft Design.

Crucially, the learning outcomes are mapped against EQF Level 7 descriptors. Learners are required to independently design and conduct experiments, interpret massive sets of complex datasets utilizing advanced mathematics and engineering sciences, and operate within multi-disciplinary teams to resolve highly unstructured engineering anomalies. The integration of high-stakes R&D projects serves as a key mechanism for achieving these outcomes by enabling students to engage with authentic engineering problems that extend beyond the controlled conditions typically associated with classroom-based learning, transitioning the educational experience from simulated classroom exercises to applied industrial research (Qian *et al.*, 2022).

6. Operationalizing RBL: ASTROBEAT, SBORAEK and STEAM

The theoretical principles of RBL are contextualized and operationalized within the MCAST curriculum through the integration of flagship R&D initiatives. These projects act as educational boundary objects, providing learners with exposure to contemporary orbital mechanics, advanced materials science and stringent spaceflight safety standards.

6.1 ASTROBEAT

The ASTROBEAT project investigates *in situ* repair strategies for spacecraft hull damage caused by micrometeoroids and space debris. From an engineering perspective, cold-welding, where similar metallic surfaces fuse in a vacuum due to atomic diffusion, is typically regarded as a significant failure risk in space mechanics. ASTROBEAT investigates whether this phenomenon can be harnessed as a low-force repair mechanism for perforated exostructures. Supported by Xjenza Malta, the project demanded extensive ground laboratory characterization to accurately map tribological parameters and contact forces (Barilaro *et al.*, 2023, 2025). The experimental setup is housed within a compact 1U cube Nanolab installed on an International Space Station (ISS) rack, carefully designed to adhere to strict acoustic and electromagnetic interference standards (Barilaro *et al.*, 2025). The payload integrates four dedicated material test beds containing CuSn4 and Al-2024T samples, a hull perforation repair device, and custom electronic and data acquisition subsystems managed by a Raspberry Pi microcontroller (Barilaro *et al.*, 2025).

A significant stage of the project involved the physical development, testing and deployment of this experimental rig aboard the ISS via the SpaceX CRS-31 mission on November 5, 2024, to validate the cold-welding process in authentic microgravity (Barilaro *et al.*, 2025). The core experiment involves preloaded springs that deliver controlled forces to the metal pairs to simulate patch applications for spacecraft hull breaches. A pico-camera monitors the actuation process, while an Electrical Contact Resistance (ECR) measurement system provides real-time data on the welding progression (Barilaro *et al.*, 2023, 2025). For MCAST master's students, engagement with ASTROBEAT extends beyond theoretical study. Students are required to analyze real telemetry data, evaluate the extreme volume/mass constraints of microgravity experimental design and navigate the complex safety and integration protocols demanded by NASA and Voyager Space. This multidisciplinary synthesis encourages students to critically evaluate conflicting design variables, construct robust spaceflight-ready hardware and process data comparing ground-based tests with orbital results to assess joint integrity and grain boundary refinement (Barilaro *et al.*, 2025).

6.2 SBORAEK

Operating in parallel to ASTROBEAT, the SBORAEK project focuses on pre-impact structural resilience and the rapid prototyping of functional satellite shields against hypervelocity impacts (HVI) (Lopresti *et al.*, 2026). Also funded by Xjenza Malta, SBORAEK utilizes a novel dual-filament 3D-printing process that embeds a continuous aramid fiber core (Kevlar) within a rigid carbon fiber-reinforced polymer (CFRP) structural matrix (Lopresti *et al.*, 2026). The methodology deeply integrates complex computational simulation utilizing Smoothed-Particle Hydrodynamics (SPH) software to predict fragmentation patterns under extreme kinetic stress and perform multi-objective optimization of the shield geometries before physical manufacturing (Lopresti *et al.*, 2026).

The physical validation of these printed shields was conducted using the "Hermes" two-stage light-gas gun at Thiot Ingegnerie's Shock Physics Lab, simulating hypervelocity orbital collisions (Lopresti *et al.*, 2026). The test campaign subjected both single-wall and multi-wall shield configurations to impacts from aluminum and steel projectiles traveling at velocities ranging from 3 to 5.2 km/s (Lopresti *et al.*, 2026). High-speed Phantom V2012 cameras and soft ballistic gel catchers were deployed to record and analyze the fragmentation debris cloud, enabling the extraction of residual and radial velocities of the fragments. Within the Master's curriculum, SBORAEK provides a practical application of advanced composite engineering and ballistic physics. Students engage directly with the complex fracture mechanics data generated by the light-gas gun tests. They are tasked with evaluating the efficacy of varying additive manufacturing parameters – such as comparing horizontal versus vertical printing orientations on delamination resistance – correlating sophisticated SPH computational simulations with empirical impact data, and proposing structural optimizations (Lopresti *et al.*, 2026). This exposure to high-velocity impact dynamics contributes to students' understanding of spacecraft survivability in increasingly congested low Earth orbits environments and informs the design of shielding solutions intended to disperse the kinetic energy of impacting debris.

6.3 STEAM activities and transdisciplinary learning

Beyond the mechanical and physical experimentation of the ASTROBEAT and SBORAEK missions, the program incorporated a STEAM (Science, Technology, Engineering, Arts and Mathematics) framework centered on the concept of "Music from Space" (Barilaro and Marciano, 2025). This approach linked spacecraft repair research activities with original musical compositions streamed directly from the ISS, translating highly technical astronautical concepts into an accessible, transdisciplinary auditory experience (Barilaro and Marciano, 2025). Two principal compositions anchored this pedagogical and cultural effort: "Moon Seeds" and "Black Sun" (Barilaro and Marciano, 2025). "Moon Seeds" is a neo-classical collaboration featuring Grammy-nominated cellist Tina Guo and composer Steve Mazzaro, which physically incorporates authentic NASA soundscapes into its acoustic production, drawing inspiration from the Apollo 14 Moon Trees (Barilaro and Marciano, 2025). Conversely, "Black Sun" operates as an experimental piece strictly built upon the NASA sonification of a black hole located within the Perseus galaxy cluster, accompanied by celestial choreography from quantum physicist-ballerina Merritt Moore (Barilaro and Marciano, 2025). By utilizing these astronomical sonifications as a baseline, the project provided learners and audiences with alternative modes of engaging with astrophysical phenomena through nonlinear, perceptual frameworks.

The actualization of these soundscapes required significant technical innovation, effectively transforming a standard audio recording session into an applied physics experiment (Barilaro and Marciano, 2025). In a strategic partnership with the New York University Abu Dhabi (NYUAD) Arts Center and the student-run Gazelien Records lab directed by Prof. Matteo Marciano, the recording of "Black Sun" necessitated unconventional acoustic capture methodologies (Barilaro and Marciano, 2025). To successfully merge human piano performance with the low-frequency astrophysical data of the Perseus black hole, engineering students deployed microphones beneath the piano soundboard and deep inside the instrument's frame (Barilaro and Marciano, 2025). Crucially, the student engineering team utilized geophone microphones – instrumentation typically reserved for measuring planetary seismic activity – coupling them directly to the piano's body and the stage platform (Barilaro and Marciano, 2025). This technical application captured sub-audible, infrasonic vibrations, effectively extracting the tactile, "seismic" resonance of the instrument (Barilaro and Marciano, 2025). This experimental methodology required students to operate within a professional-grade engineering environment where precise technical decisions directly manipulated the convergence of human performance and orbital data.

The STEAM integration expanded further into direct student involvement through the NYUAD Space Music Contest, actively linking academic theory with functional orbital missions (Barilaro and Marciano, 2025). Organized in partnership with NYUAD's music and science faculties, this initiative challenged students to compose original space-inspired works (Barilaro and Marciano, 2025). The winning pieces, "No Gravity" by Nadine Kabbani and "Little Brooks" by Summer Reid, were subsequently launched as data payloads to the ISS and broadcast during a coordinated global live stream alongside "Black Sun" (Barilaro and Marciano, 2025). This provided a concrete bridge between academic coursework and real-world space operations (Barilaro and Marciano, 2025). Student engagement continued through extended WBL activities, where students retained creative and technical responsibility for subsequent project outputs. For instance, the track "Listen," composed for the Polymath Festival 2.0 and fusing piano acoustics with solar and terrestrial NASA soundscapes, was entirely mixed and mastered by student engineer Daniel Basurto under faculty mentorship (Barilaro and Marciano, 2025). This task required the systematic application of spatial imaging, equalization and dynamic compression to balance raw scientific audio data with musical harmonics (Barilaro and Marciano, 2025). The STEAM activities associated with ASTROBEAT illustrate how artistic production can be integrated within aerospace R&D to create opportunities for transdisciplinary learning. By engaging with scientific sonification, audio engineering, creative practice and space-related research, students were exposed to perspectives and problem-solving approaches that extended beyond conventional disciplinary boundaries. These experiences suggest that STEAM-based activities may complement traditional engineering education by encouraging creativity, collaboration and alternative modes of scientific engagement (Barilaro and Marciano, 2025).

7. Discussion: educational impact and competency acquisition

The evaluation of integrating live aerospace R&D projects into postgraduate vocational education suggests a significant pedagogical shift within the MCAST aerospace ecosystem. The data suggests that transitioning learners from passive recipients of theoretical content to active participants in authentic engineering processes, characterized by technical uncertainty, multidisciplinary friction, stringent documentation requirements and absolute operational constraints, fundamentally alters the educational dynamic. This model aligns academic progression with the realities of contemporary aerospace research and industrial practice.

One of the main findings is that the projects support the development of EQF Level 7 competencies. The integration of projects like ASTROBEAT and SBORAEK mandates that students engage simultaneously with advanced engineering theory, systems-level problem-solving, experimental physical validation and regulatory awareness. Unlike conventional coursework predicated on predefined laboratory outcomes, these initiatives expose learners to incomplete datasets, unexpected hardware limitations and iterative, highly constrained design processes. Consequently, students are compelled to exercise high-level engineering judgment, evaluate critical mass/power trade-offs, justify methodological deviations and adapt their technical strategies under evolving physical conditions. This exposure appears to cultivate the forms of cognitive and professional activity expected from postgraduate engineers operating within high-reliability sectors.

The projects also contribute to the development of professional identity and independent research skills. Students interact with industrial documentation standards, complex systems engineering methodologies and international collaboration frameworks that are functionally impossible to reproduce within purely simulated academic environments. Exposure to ECSS-inspired workflows, stringent orbital mission constraints, hypervelocity materials testing procedures and rigorous payload safety reviews introduces learners to the actual organizational culture of aerospace engineering. This cultivates a mature understanding of professional responsibility, risk management and the indivisible relationship between technical innovation and operational safety.

STEAM activities provide an additional dimension to the curriculum by encouraging creativity and interdisciplinary thinking. Within the context of the ASTROBEAT and SBORAEK data, transdisciplinary approaches, such as data sonification and multimodal interpretation, encourage learners to bypass strictly linear problem-solving frameworks. While empirical literature quantifying STEAM integration in advanced aerospace engineering remains developing, the findings indicate that these methodologies foster creative reasoning, systems-level thinking and alternative modalities of pattern recognition. Specifically, the interaction between sonic representation and raw engineering datasets stimulates exploratory thinking when analyzing complex, chaotic physical phenomena associated with structural stress and hypervelocity impacts.

From a strategic and regulatory perspective, the relationship between vocational education and national space-sector development is critically illuminated. Malta’s intentional transition toward deep participation in the European space economy requires not only legislative infrastructure (e.g. the Malta Space Act) and funding mechanisms but a highly specialized workforce capable of driving applied research. In this respect, the MCAST aerospace program functions as a strategic interface linking academia, industry and emerging national space policy. The integration of active R&D projects contributes simultaneously to student training, high-TRL institutional research output and national capability development.

The ESA PECS framework serves as a particularly important enabler within this ecosystem. Access to collaborative European structures, restricted funding calls and established technical networks provides crucial financial support and rigorous external validation for the research activities embedded in the curriculum. Students participating in projects influenced by ESA standards gain significant exposure to established procurement structures, documentation practices and quality-control expectations. Furthermore, the anticipatory integration of impending standards from the proposed EU Space Act into the curriculum guarantees that graduates possess an intuitive, internalized understanding of the complex legal and environmental responsibilities (such as space debris mitigation and cyber-resilience) inherent in modern orbital operations.

Nevertheless, the implementation of RBL within aerospace VET presents notable logistical and operational challenges. High-stakes R&D environments are resource-intensive, placing substantial demands on faculty and institutions. Developing orbital hardware for the ISS, conducting hypervelocity tests abroad, managing international consortiums and supervising unstructured postgraduate research require significant institutional commitment in terms of funding, laboratory infrastructure and administrative coordination. Assessment practices also require radical calibration; evaluating student performance across collaborative technical design, hardware simulation, systems integration and data analysis tasks is considerably more complex than grading standardized examinations. Institutions must therefore develop highly transparent assessment strategies capable of recognizing disparate individual contributions while maintaining strict academic consistency.

While this study provides a comprehensive framework for integrating RBL into vocational aerospace education, several limitations must be acknowledged. First, the analysis relies predominantly on desk-based qualitative literature review and curriculum evaluation rather than longitudinal quantitative data. Consequently, the direct long-term impact of these initiatives on graduate employability and career trajectory remains to be empirically validated. Second, the study is situated within the specific institutional context of MCAST and the Maltese aerospace sector; therefore, the findings may not be uniformly generalizable to larger institutions or nations with fundamentally different regulatory and industrial landscapes. Finally, as the study is authored by faculty directly involved in the ASTROBEAT and SBORAEK projects, interpretations of the pedagogical outcomes may be subject to inherent researcher positionality, despite rigorous efforts to apply epistemic reflexivity.

8. Conclusion

This study has systematically examined the integration of live aerospace R&D initiatives within the MCAST MSc in Aerospace Engineering, providing a framework for advancing postgraduate vocational education in emerging space-sector environments. Through a comprehensive qualitative review of pedagogical theory, European policy frameworks, digital learning paradigms and empirical institutional practices, the research suggests that RBL constitutes a key and academically very important mechanism for bridging the longstanding divide between theoretical engineering instruction and applied industrial research.

The analysis of the ASTROBEAT and SBORAEK projects illustrates how authentic, high-stakes aerospace research activities can be structurally transformed into educational environments that cultivate advanced EQF Level 7 competencies, mature professional judgment, interdisciplinary collaboration and profound research autonomy. By engaging directly with orbital payload deployment, hypervelocity impact analysis, advanced composite materials testing, strict systems engineering workflows and complex regulatory compliance, postgraduate learners are immersed in forms of engineering practice that extend substantially beyond conventional classroom abstractions. These functional experiences strengthen the alignment between vocational academic curricula and the stringent operational requirements of the international aerospace sector.

The study further establishes that the educational efficacy of these R&D projects is significantly amplified when hybridized with carefully structured andragogical frameworks, blended-learning methodologies and transdisciplinary STEAM approaches. Integrating artistic and multimodal methods, particularly data sonification for interpreting chaotic impact datasets, introduces critical dimensions of creativity and cognitive flexibility that are becoming increasingly indispensable within future aerospace R&D environments. However, the research emphasizes that these progressive approaches must be implemented critically and systematically, thoroughly scaffolded to prevent student cognitive overload. Crucially, the findings position the MCAST aerospace program within the broader strategic evolution of Malta as an emerging space nation. Educational institutions operating within smaller member states can wield a decisive influence on national innovation ecosystems when academic activity is tightly synchronized with industrial research, regulatory evolution (such as the EU Space Act and Malta Space Act) and international cooperation structures like ESA PECS. In this capacity, the program transcends mere workforce preparation; it acts as an engine for research capacity building, international technological visibility and long-term institutional maturation.

The implementation of RBL in aerospace education is, however, accompanied by notable structural limitations. The model demands sustained investment in laboratory infrastructure, specialized test equipment, faculty expertise, digital learning systems and international collaboration networks. High-stakes engineering projects introduce significant pedagogical complexities regarding transparent assessment, workload management and student psychological support. Institutions adopting similar frameworks must vigilantly balance technological innovation with realistic operational planning and rigorous QA protocols.

This article concludes that RBL offers a valuable framework for strengthening the relationship between postgraduate vocational aerospace education and contemporary aerospace practice. The findings suggest that the integration of authentic R&D activities within the curriculum can support the development of high-level technical competencies, professional judgement, research autonomy and interdisciplinary collaboration. Within emerging space-sector environments such as Malta, these approaches have the potential to contribute not only to student learning, but also to institutional research capacity and broader national innovation objectives. As the aerospace sector continues to evolve in response to increasingly complex technological, regulatory and operational challenges, educational programs will need to ensure that graduates are prepared not simply to apply existing knowledge, but to participate actively in the creation of new knowledge through research, innovation and collaborative problem-solving.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the main author, a non-native English speaker, used AI-assisted tools such as Grammarly, QuillBot and ChatGPT to refine the document, check for language errors and improve clarity beyond the capabilities of Microsoft Word's spell-check function. Following the use of these tools, the author reviewed and edited the content as necessary and takes full responsibility for the final content of the document.

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