The Case for Data Science, Automation, AI and Programming Integration Into an Aeronautical Engineering Technology Curriculum

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Abstract

Aviation and Aerospace graduates face growing challenges of accelerated, continuous learning as industry advances rapidly in digitization and automation of nearly every aspect of work. Graduates are at risk of falling behind in critical supporting competencies like data science, and basic IIoT skillsets, necessary to amplify existing technical capabilities to work-ready levels. This paper highlights an observed demand shift in workforce readiness that includes more fluency in IIoT and Data Science philosophies and practices. Implications for educators and the related demand for changing content and pedagogical approaches for grafting these new paradigms into existing, foundational teaching and learning constructs are highlighted. A training module curriculum piloting basic introduction to programming, coding and robotics for undergraduate seniors in an aeronautical engineering technology program, using remote controlled and Augmented Reality camera systems to practice maintenance tasks is also discussed.

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Introduction

Much of global life is structured around the speed of commerce, defense, on-demand leisure activity, access to goods, services and other vital connections to the world afforded by aviation and aerospace. These industries contribute to daily personal and business life, economic development and growth worldwide. They generate $3.5 trillion in economic contribution, 87.7 million jobs and 4.1% of the global Gross Domestic Product (Air Transport Action Group, 2020, p. 10).

The Air Transport Action Group (2020) further reported if the aviation industry was a country, it would be the 17th largest economy in the world. With an industry so pervasive, vast and fast moving, technology evolutions they undergo also impact the manner in which educational institutions prepare the future workforce. Students in technical education programs like Aeronautical Engineering Technology enter a variety of aviation, aerospace and commercial space career fields demanding increased fluency in digital tools and skills. An international survey of aerospace and aviation workforce challenges showed basic programming, robotics, and automation skills ranked nearly as high as technical skills among mandatory workforce competencies needed by 2030 (Ropp, et. al, 2020).

Literature Review

A review of literature revealed that understanding of basic programming, robotic behaviors/capabilities and general principles of automation were highly valued within the aviation, aerospace and commercial work domains. Prominent search returns were from aviation, aerospace and related maintenance, manufacturing and engineering fields; university aviation and engineering education institutions. These domains were further evaluated to identify and group commonly used descriptions and application, using keyword descriptors: “robotics”, “data science”, “automation” “programming” individually, and also coupled with industry word modifiers of “aviation”, “aerospace”, “commercial space”, “aircraft” and “aircraft maintenance”. Truncation and Phrase Searching methodology was used.

Five databases were used, including:

1. Academic Search Complete
2. ScienceDirect
3. Engineering Village
4. Science Citation Index
5. PsycInfo Database

Additional sourcing also came from industry trade publications and websites. Source returns were then evaluated for frequency of keyword descriptors and categorized into the following topical areas, relative to the role of workforce upskilling/pivoting to learn advancing technologies, and entry level skills needed for new entrant graduates from current aviation and aerospace education programs. Topical areas identified were:

1. Automation in aviation and aerospace
2. Challenges and implications for higher education
3. Data science
4. Robotics

Automation in the Aviation and Aerospace Industry

The aviation and aerospace industries have been continuously integrating Industrial Internet of Things (IIoT), Big Data frameworks, automation and robotics in various forms into daily operations for several years. More recently, rapid advances in computing and concepts like the digital thread, digital twin, edge computing, machine-to-machine learning (M2M), and Artificial Intelligence (AI) mean these data science tools are now a part of the everyday tools and operations language, not just for producing, but in green initiatives and sustainability in reducing waste streams and emissions (Anand, 2022). Even traditional machining processes, like CNC operations, have advanced to virtual simulation and digital twin capabilities, assessing and adjusting pre-programmed cutting paths with real-world cycle time predictions. This in turn reduces time for set-up procedures and machine stoppage on the live process while enabling greater accuracy (Webster, 2022). The move toward automation was further accelerated through 2020 as companies sought – and continue to seek- solutions for worker shortages, high demand, order backlogs, and greater levels of operational safety (Crow & Dabars, 2020). Optimization in the Aeronautical Engineering fields includes areas such as aerodynamics, structural analysis, materials, and avionics and integration of new automation into tried-and-true processes and procedures has boosted this progression (Goetzendorf-Grabowski, 2017).

Graduates entering the modern workforce are expected to possess at minimum cursory knowledge and cross-over skills incorporating these IIoT/AI frameworks (Crow & Dabars, 2020; Zaatari, Marei, Li & Usman, 2019). Gaming technologies like Augmented, Virtual and mixed/parallel reality have also migrated to front line work and are being incorporated and tested in technical teaching and learning environments (Borgen, Ropp & Weldon, 2021) in addition to the industry, creating ‘digital learning and workspaces’ above and below the wing.

These technologies are no longer found only in advanced manufacturing on-board Health Management and Systems Maintenance computers, or system FADECs. Robots have migrated to realm of Maintenance, Repair and Overhaul (MRO), an arena historically considered a human-only, mostly ‘touch work’ domain. “Cobots”– *collaborative robots*, now share workspaces with human workers, with both human and machine learning as they go. Robots cling to the sides of a fuselage and perform technically involved inspections and repairs (Schmutzler, 2022). Lufthansa Technik boasted a flight deck avionics robot being tested for switch and light control operations, reporting reduced human labor by up to two hours on certain tasks (Lynch, 2019).

An automated milling robot, capable of *in situ* scanning the external carbon-fiber-based fuselage and wing structures of an Airbus A350 can develop and execute a precise scarf joint and milling pathway, as it clings to the fuselage or wing surface (Lufthansa Teknik, 2020; Read, 2018).

One study showed almost 77% of companies incorporating technology from across industry sectors reported significant difficulty retaining qualified technical workers (Association for Advancing Automation, 2022; Formic White Paper, 2022). As a result, many companies are turning to automation for survival in order to bridge the operational gap caused by labor shortages (Association for Advancing Automation, 2022; Manfredi, 2022). This surge in automation and co-robotic workspaces increases the demand for the agile, continuous learning workforce. Recent research of international aviation and aerospace companies however, reported workforce challenges and gaps in keeping up with current with these and related data technology innovations, which outpace workforce adaptation (Ropp et al., 2020) causing skill gaps and competency challenges in both existing workers as well as newly hired aviation and aerospace graduates (Ropp & Belt, 2020)

Sharpening the pedagogy and workforce talent pipeline

Learning 'with' not just 'about' new technologies

Disruptive advances in computing technology, shifting global trade and supply chains, regulation and political climates, and constantly reshaping business and operating models now demand a more resilient, agile workforce (Hedden, 2020) which directly impacts upstream education. Traditional pedagogy and applied learning approaches for a new age of digital fusion of modern technologies into legacy aviation/aerospace operations occurring within the industry must evolve (Ropp, et al, 2020). Graduates from Part 147 maintenance schools as well as broader spanning aeronautical engineering technology programs are being hired into sectors across the aviation, aerospace and commercial space industries where robots and programming are common place competencies within work processes. Eric Acton (2019), Head of Innovation Ecosystems for the Applied Technology Group at Rolls-Royce stated at a Data Science workshop, "workers, graduates coming in, need to become *second-domain* experts in other skills complimentary to their technical skills to take on expected problem-solving". (E. Acton, personal remarks, November 12, 2019).

The challenge for higher education

Rapid, relevant and continuous learning must be embraced and integrated more deliberately and uniformly in higher education if it is to remain competitive and a source of value for learners. Society in general, and the industry in certain operations, now question the value proposition of the cost and timelines for a traditional degree. A rapid shift to traditional apprentice-style learning and employee upskilling, especially for non-degreed personnel on precise skills is paying off for companies and employees alike.

One aerospace workforce model emphasizes interpersonal competencies that explicitly list *inquisitive*, *resilient*, and *critical thinking* approaches to open-ended, problem-based scenarios (U.S. Dept. of Labor, 2018) and interpersonal resilience competencies were found among top attributes sought in new aviation and aerospace graduates (Ropp & Belt, 2020). These are also a major focus and challenge for the exiting aerospace workforce (Ropp et al., 2020). Research also shows that a lack of these competencies poses a direct threat to safety, reliability and economic viability of the industry (Gohardani, 2018; Hedden, 2020; Mickeler, 2020).

In their writing on the fifth wave evolution of American universities, Crow & Dabars (2020) further emphasize the need for pedagogical innovation. They emphasize resilient approaches to university education's own teaching and learning delivery format, calling for transformation of traditional academy practices to be more deliberately outward facing resources for "continuing education to society, acting as providers of retraining and upskilling for learners" (p. 23). They characterize the vision for the university evolving to that of a knowledge enterprise (p. 7), partnered with industry and the notion of continuous learning as a key competency.

Gingrich, (2021) writes of a "coming revolution" and transformation in the American higher education system, asserting collegiate education is rapidly becoming viewed as less necessary, as active learning apprenticeships become more popular. Challenging collegiate/university education, Gingrich shared that the message given to young people from companies today is "they'll train them for the job role, and incorporate online learning to supplement their education as they go" (Gingrich, 2021).

Data Science – Making sense of mass data

Data Science has been described as a new discovery paradigm and potentially one of the most significant advances of the early 21st century (Brodie, 2019). It involves techniques of extracting and analyzing large volume, high velocity data, using multiple sources and tools, then compiling it into some meaningful, *actionable* and useful knowledge (Brodie, 2019). The most prominent use case in aviation and aerospace operations is the broadening use of real-time and predictive maintenance (PdM) calculations in which the system can rapidly simulate mission cycles, look at predicted failure modes and suggest tailored repair or maintenance interval strategies. With smart air vehicles come more data being generated than ever before. For scale, consider an older Airbus A320 historically generated around 400 data points from its onboard sensor technologies; the A330 over 1400, and the A350, first delivered back in 2014 generates upwards of 400,000 data points (Read, 2018). Younger learners already use platforms that rely on data science frameworks for their functional algorithms, specifically in social media and online gaming platforms.

Robotics

In the United States during the first quarter of 2022, orders for industrial workplace robots increased 40%, with a majority of these orders being non-automotive (Manfredi, 2022). Yet the U.S. is behind other global industrial forces. The U.S. had just 1.6 robots per thousand workers just six years ago. China remains the dominant market giant in automation, mostly through its manufacturing sectors and is among the top five countries premier in automation

(Formic, 2022, pg. 3). Other countries like Germany have 7.6 robots per thousand German workers.

What defines a robot can be difficult, even for leading professionals within the robotic industry. Gil Pratt, CEO of the Toyota Research Institute defines a robot by "what it does and how it does it…senses, thinks and acts". He further scopes the context and use case, where job tasks are "dull, dirty or dangerous" (Pratt, 2022). This concept is also shared in the aviation MRO world where robots can be utilized for dull, repetitive tasks (Lynch, 2019).

Other definitions include: a machine using sensing inputs, processing calculations and some type of cognitive assessment to determine and execute a task - essentially, a non-human autonomous system using machines and sensors that detect, compute, and together act on the environment (IEEE, 2022). Pratt (2022) indicated that given these attributes which ultimately act upon and influence the proximal environment, technically a household thermostat could be considered a robot.

Programming and Robotic Integration Training Module Pilot

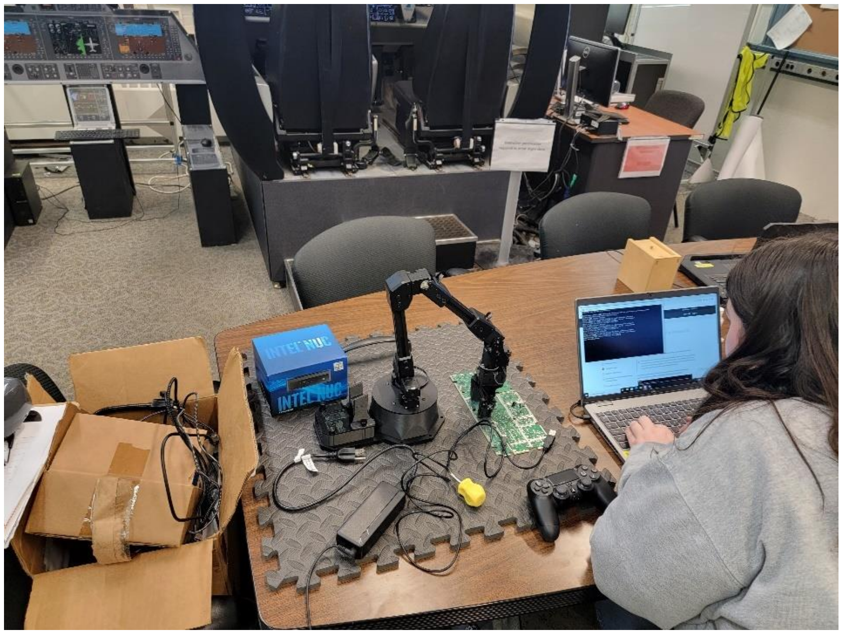
Pilot Module Design

In March 2023 two work stations comprised of a computer and a desktop robotic arm with a PS4 gaming controller were designed as a two-session self-guided programming lab for students in a senior capstone course, Aircraft Airworthiness Assurance. This course is part of the Aeronautical Engineering Technology (AET) degree program in the School of Aviation and Transportation Technology.

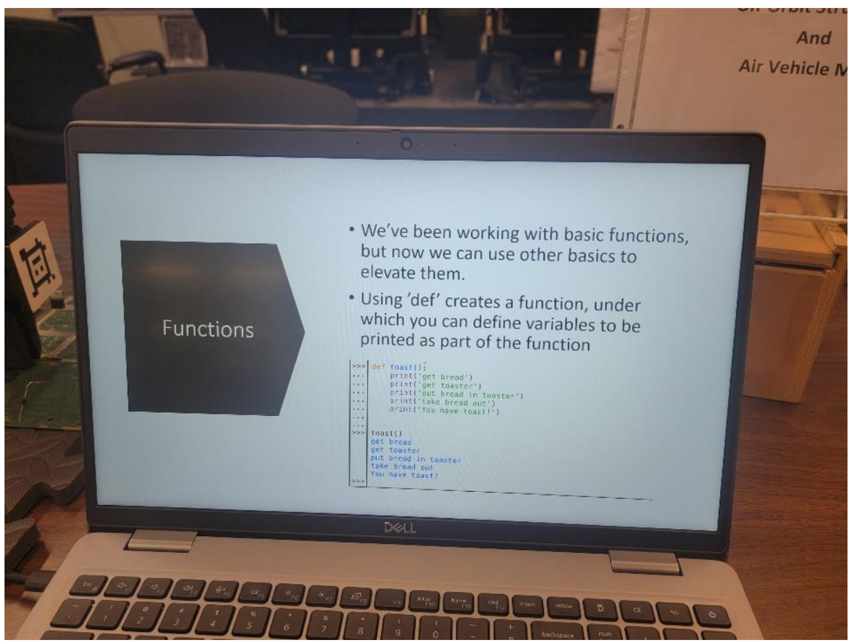
Designed by a senior AET project student, these were comprised of a laptop computer with a two-module Introduction to Programming Language using Python, and programming practice sessions in PowerPoint. These were followed by applied practice using two Trossen-200 controllable programmable robotic arms with five degrees of freedom (Figure 1).

Figure 1

MRO robotic work station design and test



AMT-I Center's *Hangar of the Future*, 2023



AMT-I Center's *Hangar of the Future*, 2023

A two-module curriculum covering basic programming, coding and automation and oriented toward aviation and aerospace maintenance and assembly tasks was developed for piloting into a senior level AET capstone course. It consists of beginner, intermediate, and advanced theory sections as well as applied practice with the remote-controlled robotic arm (Table 1).

Table 1

Automation, Robotics, and Programming Curriculum for AET Learners

Module	Topic	Concept
1	Programming Overview	Overview of importance of learning programming and what Python is
1	Basics and Operation	How to download and open Python for those who have never done so before
1	Concepts Part 1: Beginner	Printing, Variables, and Naming
1	Concepts Part 2: Intermediate	Loops, Strings, and Ranges
1	Concepts Part 3: Advanced	Basic Functions, Functions with Variables, Functions with Loops
2	Robotics and Automation Overview	Overview of importance of learning about automation and what robots, Cobots, and automation are
2	Automation in Industry	Break out of students into groups where they will brainstorm uses for automation in industry. Then some examples currently in use will be shared with the class.
2	Robots Introduction	Introduce students to the robot arm and the subsequent procedures and information.
2	Robot Arm Activities	Students will be split into groups and will complete exercises using the robotic arm in the Hangar of the Future.

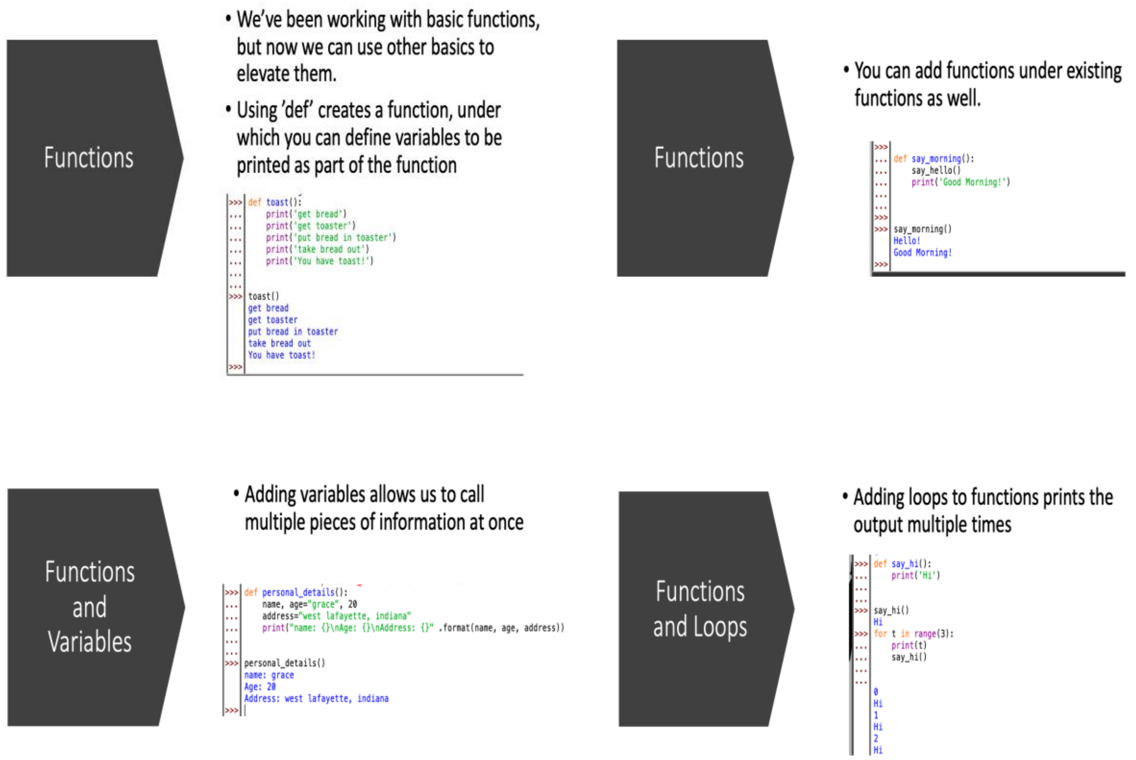
Courtesy: Grace Cronin, 2023

Module 1 was designed as a self-learning review and coding orientation in Python programming language. Since some learners have previous coding experience, the module was developed with three learning tracks: Beginner, Intermediate, and Expert. Learners are able to self-determine their existing level of knowledge, and begin a learning track from that point.

Students practice programming basic lines of code in Python, including printing commands, functions, naming variables, loops, strings, and incorporating variables into their functions (Figure 2).

Figure 2

Module 1: Python coding practice exercises (Courtesy: Grace Cronin, 2023)



The AMT-I Center's *Hangar of the Future* laboratory has two robotic arms, allowing students to be divided into simultaneous learning sections:

1. Self-learning introduction/programming theory and coding practice
2. Hands-on practice using a gaming controller and Augmented Reality camera-based target system.

Once underway, students are therefore able to practice theory, coding, and hands-on application potentially within one 3-hour lab. Module 2 content focuses on task automation with applied practice using two Trossen-200 programmable, *five degrees of freedom* robotic arms (Figures 3 and 4 following).

Figure 3

Robotic arm work station

AMT-I Center's *Hangar of the Future*, 2023

Figure 4

Robotic arm remote manual grasp and autonomous part selection

Discussion

Development of a pilot training module on programming and basic use of robotics in a university aeronautical engineering technology educational setting began in Spring 2023 and is ongoing. This report presents a Phase-I proof-of-concept to evaluate student user adoption, ease of use, and assess overall applicability in an AET laboratory environment. Phase II full station operation, refined task development and user testing are underway.

There is a need to enable a future and existing technical workforce to meet continuous upskilling demands in aviation and aerospace domains. Companies continue investing in robotics and automation to cover growing competency and retention gaps. Global demand for aviation and aerospace services is still predicted to continue to grow over the mid and long term (Federal Aviation Administration, 2020a), with increasing demand for qualified professionals with cross-functional technical skills, including automation and basic programming as basic competencies. Small active-learning modules applied to exiting curriculum offer one answer to expanding to meet the new age learning needs of AET students.

Conclusion

There is compelling evidence of a need for university/collegiate level education, especially in aviation and aerospace, to embrace new technologies and leverage these within the teaching and learning paradigm. To learn with, not just about. Exploratory and collaborative teaching and learning are excellent frameworks for enabling students to think in terms of visionaries, innovators and pioneers, taking on real-world challenges to workforce readiness in real-time. Higher education systems must use this technology to facilitate and demonstrate more rapid learning and utility if we are to stay relevant and competitive in preparing the next generation workforce.

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