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Abstract	Additive Manufacturing (AM) is a growing technology with transformative potential across industries. However, the adoption of AM is hindered by the lack of a skilled workforce. This article examines the role of industry-government collaboration, reskilling and training strategies, and certification pathways in empowering the AM workforce. Using case studies from Singapore, we discuss the challenges and opportunities in this area. The article concludes by calling for coordinated efforts from industry, government, and educational institutions to empower the AM workforce and accelerate the adoption of this technology.

Keywords (separated by '-')	Additive manufacturing - 3D printing - Collaborative training - Workforce development - Continuous professional development - WSQ certification

Empowering the Additive Manufacturing Workforce: Industry-Government Collaborative Training, Reskilling Strategies, and Certification Pathways

Chen-Nan Sun and Huey Yuen Ng

Abstract Additive Manufacturing (AM) is a growing technology with transformative potential across industries. However, the adoption of AM is hindered by the lack of a skilled workforce. This article examines the role of industry-government collaboration, reskilling and training strategies, and certification pathways in empowering the AM workforce. Using case studies from Singapore, we discuss the challenges and opportunities in this area. The article concludes by calling for coordinated efforts from industry, government, and educational institutions to empower the AM workforce and accelerate the adoption of this technology.

Keywords Additive manufacturing · 3D printing · Collaborative training · Workforce development · Continuous professional development · WSQ certification

1 Introduction

The manufacturing landscape is undergoing a transformation driven by the emergence of Additive Manufacturing (AM), also known as 3D printing [1]. While AM offers significant benefits, it is important to acknowledge that it also has limitations, such as a limited selection of materials and potentially higher costs for certain applications. However, the technology is evolving, and these limitations are expected to diminish over time.

Recognising the potential of AM, Singapore has focused on building a skilled workforce to support this field. A key pillar in achieving this goal is the Singapore Workforce Skills Qualifications (WSQ). While not specific to AM, the WSQ is a certification system that provides a structure for career progression across various industries [2]. As shown in Fig. 1, it offers individuals a clear pathway to develop

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Fig. 1 The different WSQ qualifications levels

their skills and knowledge, with qualification levels ranging from WSQ Certificate (basic skills) to WSQ Graduate Diploma (advanced expertise).

This structured approach is adaptable and can be applied to acquiring the foundational skills and knowledge necessary for various industries. While not all levels may be directly applicable to every industry or specialisation, the WSQ system provides a foundation for building relevant skills and knowledge. The WSQ establishes skill requirements through a collaborative effort involving the government, industry leaders, and key stakeholders. These stakeholders include employers, industry associations, unions, professional bodies, and education and training providers. This ensures the training equips individuals with the skills and competencies needed to succeed in various job roles [3].

This close collaboration fosters alignment between the education system and industry needs, ensuring graduates are equipped with the knowledge and skills employers seek. Moreover, the modular structure of WSQ qualifications allows for flexible learning and upskilling. For instance, individuals can obtain specific modules within an AM-related qualification or pursue the entire programme, depending on their career goals and desired level of expertise.

Singapore's focus on workforce development in AM goes beyond basic qualifications. Through collaboration between industry and government, the nation offers advanced training programmes like the WSQ Graduate Diploma [4] and WSQ Specialist Diploma [5] in Additive Manufacturing. These programmes provide in-depth expertise in AM, preparing professionals to address complex challenges in the field. This collaborative approach ensures that training programmes remain current with the latest advancements in AM technology and industry trends.

This chapter begins by examining the role of Singaporean government initiatives in building a skilled workforce, focusing on the SkillsFuture framework and the implementation of WSQ qualifications in AM. It then introduces reskilling and training strategies, including the creation of specialised programmes developed in response to challenges like the COVID-19 pandemic. Finally, the chapter discusses the importance of certification pathways and continuous professional development

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in preparing an adaptable AM workforce. Through case studies from Singapore, it offers practical insights for policymakers and industry stakeholders working to strengthen the AM ecosystem.

2 Industry-Government Collaboration for Additive Manufacturing Training

2.1 SkillsFuture Singapore (SSG) and the Skills Framework

The advancement of society and technology brings both opportunities and challenges. SkillsFuture Singapore (SSG), a statutory board under the Ministry of Education (MOE), addresses these challenges through the national SkillsFuture movement [6]. This initiative promotes lifelong learning and strengthens the ecosystem of education and training across industries. SSG's efforts go beyond mere training delivery; it fosters collaboration between industry partners, training providers, and educational institutions to ensure curriculum development reflects the latest advancements in technology and industry needs.

Recognising the need for a training infrastructure to develop an adaptable workforce, SSG leverages industry-government collaboration through initiatives like the Skills Framework. This framework currently supports 36 industry sectors, including Accountancy, Healthcare, and Workplace Safety and Health [7]. Each framework is tailored to its respective industry and provides information on employment trends, career pathways, in-demand job roles across various skill levels, and the specific skills and competencies required for each.

Within these frameworks, career pathways are mapped to skill sets at different stages, such as entry-level, mid-career, and leadership roles. The Skills Framework helps individuals identify WSQ qualifications that align with their career goals, enabling informed decisions about training programmes.

For Additive Manufacturing, the framework is part of the Precision Engineering sector, providing guidance on the skills and competencies needed in this field. This alignment highlights how the Skills Framework supports industry transformation while preparing individuals to succeed in evolving fields like AM.

The Singapore government supports AM training through funding programmes administered by SSG. These programmes significantly reduce the cost of SSG-supported courses, making it more accessible to a wider pool of learners. Examples include the SkillsFuture Credit [8] for Singapore Citizens aged 25 and above, the Mid-Career Enhanced Subsidy (MCES) [9] for those aged 40 and above, and the Enhanced Training Support for SMEs (ETSS) [10]. These initiatives ensure affordability, particularly for courses offered by SSG-appointed Continuing Education and Training (CET) Centres [11]. Details on specific funding programmes are provided in Table 1.

Table 1 Selected SkillsFuture Singapore (SSG) funding programmes for courses offered by SSG-appointed CET Centres

Category	Funding support	For self-sponsored individuals [12]	For employers [13]	Remarks
Singapore citizens (SCs) and permanent residents (PRs)	Up to 70% of course fees	√	√	
SCs aged ≥40 years old	Up to 90% of course fees	√	√	SkillsFuture mid-career enhanced subsidy (MCES)
Small and medium enterprises (SMEs)	Up to 90% of course fees		√	Enhanced training support for SMEs (ETSS)
Persons with disabilities (PwDs)—SCs and PRs	Up to 95% of course fees	√	√	Only for eligible courses supported by SG Enable [14]

2.2 Open Access and Bite-Sized Learning with Workforce Skills Qualifications (WSQ)

In Singapore, SSG oversees the WSQ system, which plays an important role in shaping a skilled and adaptable workforce. The WSQ functions as a national credential system. It aligns training, development, assessment, and certification of skills and competencies with the needs of various industries. The WSQ is grounded in the Skills Framework, providing insights into job roles and required skills.

The WSQ system operates under a quality assurance framework, ensuring training programmes meet standards and are delivered effectively. As a competency-based system, WSQ emphasizes relevance to industry needs, open access for individuals, and a pathway for career progression. Individuals can pursue bite-sized modules that lead to a Statement of Attainment (SOA), allowing them to build their skillset progressively and ultimately achieve a full WSQ qualification. These qualifications are recognised and quality-assured by both SSG and established awarding bodies.

The open access approach of WSQ enables individuals from diverse backgrounds to participate in AM training programmes. This inclusivity fosters a wider pool of skilled professionals entering the AM workforce. Additionally, the modular structure of WSQ qualifications provides bite-sized, accessible training modules. These modules cater to busy professionals seeking upskilling or individuals aiming to acquire specific AM competencies without committing to a full programme. This flexibility supports targeted learning and caters to various needs within the industry.

2.3 WSQ Graduate Diploma in Additive Manufacturing

Driven by the aim to leverage Singapore's existing strengths in AM, a collaborative effort between industry and government led to the development of the WSQ Graduate Diploma in Additive Manufacturing, which was introduced in 2018. This programme is offered by the Singapore Institute of Manufacturing Technology (SIMTech), a research entity under the Agency for Science, Technology and Research (A*STAR). SIMTech has a strong record in advancing AM research and fostering industry adoption, making it a suitable choice for hosting this programme.

2.3.1 Course Overview

In recognition of the need for a workforce capable of applying theoretical knowledge to real-world applications, this programme adopts a pedagogical approach that differs from traditional university course models. It focuses on equipping graduates with a strong foundation in advanced knowledge, practical skills, and the ability to create real-world impact essential for roles in the AM industry.

Aligned with the Singapore Skills Framework Level 6, the programme leverages SIMTech's expertise and AM capabilities to deliver a curriculum comprising five modules, as detailed in Table 2.

The first four modules align with the Technical Skills and Competencies (TSCs) outlined in the Skills Framework for Precision Engineering. Developed collaboratively by agencies like SkillsFuture Singapore (SSG), Workforce Singapore (WSG), Singapore Economic Development Board (EDB), Enterprise Singapore (ESG), industry associations, training providers, organisations and unions [15], these modules focus on Knowledge Acquired/Ability Acquired (KA/AA). They provide participants with a holistic understanding of AM fundamentals, including the principles and methodologies behind various AM systems.

Students spend roughly half their time in the classroom and the other half in the lab, striking a balance between theoretical knowledge and hands-on experience.

Table 2 Modules offered under the graduate diploma in additive manufacturing

Module	Title	Duration (Hours)
1	Smart additive manufacturing system	45
2	Powder-bed additive manufacturing processes for complex functional metallic components	45
3	Review high speed additive manufacturing processes for metallic components	45
4	Polymer-based additive manufacturing processes for flexible mass customization	45
5	Plan and manage project for implementation	30

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This approach ensures trainees gain a clear understanding of end-to-end additive manufacturing processes, covering topics like topology optimisation, design for AM, feedstock preparation, AM processing, and post-processing techniques. By engaging in practical activities and understanding AM workflows, participants develop a solid foundation for success in the field.

The programme also equips participants with soft skills through a dedicated Critical Core Skills (CCS) module [16]. This module focuses on project management, including planning, execution, and management of technology, product, and process development in AM. Trainees learn how to apply project planning tools, navigate uncertainties and disruptions, and consider human, financial, and business factors, enabling them to effectively lead AM projects from concept to completion.

The Graduate Diploma programme is led by a team of qualified instructors with experience in both AM research and industry applications. All module leaders hold either the WSQ Advanced Certificate in Learning and Performance (ACLP) or the Advanced Certificate in Training and Assessment (ACTA) qualification, both of which meet SSG's Adult Education qualifications for Adult Educators [17]. This combination of academic expertise and industry experience ensures participants receive up-to-date training and insights.

The programme goes beyond academic knowledge from research institutes by adopting SIMTech's Learn-Practice-Implement™ (LPI™) pedagogy [18], which emphasises practical application alongside theoretical learning. For instance, to complement the curriculum, guest speakers are regularly invited to share their industry expertise. These speakers come from a range of backgrounds, including leading AM industry providers like EOS [19] and GF Machining Solutions [20], as well as local AM firms such as Creatz3D [21] and ELH Tech [22]. This interaction with industry professionals from both global and local perspectives provides participants with valuable insights into practical applications of AM technologies, bridging the gap between theory and practice, and fostering a well-rounded learning experience.

Recognising the needs of working professionals, the Graduate Diploma in AM is offered in an evening format, allowing participants to balance their studies with work commitments.

The programme prepares graduates for various roles within the AM industry, including AM Technical Lead, AM Process Specialist, AM Applications Engineer, or AM Research and Development Manager. It is suited for professionals with a background in engineering, science, or related fields who aim to contribute to the advancement of AM. Experienced AM professionals seeking to broaden their expertise and advance their careers will also benefit from the curriculum, which is designed to enhance skills and support career progression.

2.3.2 Success Stories

Graduates who complete the programme gain a competitive edge in the job market and are well- prepared to contribute to the future of AM. The Graduate Diploma in

AM not only equips participants with technical skills but also enables them to pursue new career opportunities. Some graduates have successfully transitioned from other disciplines into AM, while others have applied their knowledge to advance AM processes within their companies, including part production.

The programme's influence is also demonstrated by "Team AMPM," two graduates who used their course knowledge to win the 1 kg Challenge [23] with an innovative internal channel coolant drill design [24]. Organised by the National Additive Manufacturing Innovation Cluster of Singapore (NAMIC) [25] and ExtraBold Inc. [26], the 1 kg Challenge invites participants to create sustainable, 3D-printable designs within a 1 kg weight limit. This competition promotes Design for Additive Manufacturing (DfAM) principles, inspiring creativity and innovation in AM.

Inspired by their learnings, Team AMPM's design highlights the potential of AM for creating sustainable and complex geometries. Their success reflects the industry's emphasis on sustainability and demonstrates how AM can contribute to a greener future in manufacturing.

2.4 Additional Collaboration Examples

The Graduate Diploma in Additive Manufacturing is just one of many options available. SSG currently funds over 50 AM-relevant training courses [27], demonstrating the strong collaboration between industry and government in this field. These courses are offered by a network of partners, including Institutes of Higher Learning (IHLs), Research Institutes (RIs), and companies like Siemens, TÜV SÜD, and private training providers who are WSQ Approved Training Organisations (ATOs). This variety ensures alignment with industry practices and caters to diverse learning needs.

In addition to partnerships, experts from globally recognised standards organisations like ASTM International work with Singapore's research institutes and polytechnics to deliver specialised training programmes such as "Methods of Qualification and Certification for Additive Manufacturing" and "Additive Manufacturing for Professionals." These collaborations provide AM professionals with access to the latest knowledge and insights. See Table 3 for examples of training providers and courses.

3 Reskilling and Training Strategies for the Evolving Landscape of Additive Manufacturing

The COVID-19 pandemic underscored the importance of a skilled and adaptable workforce, particularly in industries like AM, where ongoing innovation requires the adoption of new technologies. Singapore addresses this challenge through initiatives like the SGUnited Skills (SGUS) Programme.

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Table 3 Selected examples of SSG-funded AM training courses

Training provider	course title	Remarks	Reference
Nanyang Technological University (NTU)	Qualification of parts printed by metal additive manufacturing	Offered by NTU Centre for Professional and Continuing Education (PaCE@NTU)	[28]
National University of Singapore (NUS)	General introduction of material for additive manufacturing	Offered by NUS College of Design and Engineering for Continuing Education and Training	[29]
Singapore Polytechnic (SP)	Additive manufacturing for professionals (classroom and asynchronous e-learning)	In partnership with ASTM International Additive Manufacturing Center of Excellence (AM CoE)	[30]
Siemens	Advance manufacturing (additive manufacturing) learning programme	Offered by Siemens Advance Manufacturing Transformation Centre (AMTC) Singapore	[31]
Learners Hub Pte. Ltd	Hands on in 3D printing, modelling and scanning	Training provider is a Singapore-based Small and Medium-sized Enterprise (SME)	[32]
Advanced Remanufacturing and Technology Centre (ARTC)	Industrial additive manufacturing for practitioners	In partnership with TÜV SÜD, Materialise, and EOS	[33]
Singapore Institute of Manufacturing Technology (SIMTech)	Methods of qualification and certification for additive manufacturing	In partnership with ASTM International Additive Manufacturing Center of Excellence (AM CoE)	[34]

Launched in 2020 as part of the SGUnited Jobs and Skills Package, the SGUS Programme reflects Singapore's proactive approach to workforce development during a global crisis [35]. Designed for Singaporean citizens and Permanent Residents (PRs) aged above 21, it focuses on unemployed or retrenched individuals seeking to reskill or upskill in high-growth sectors like AM. The programme requires a full-time commitment, allowing participants to concentrate on acquiring relevant skills. This approach supports the development of a workforce ready to seize opportunities in this evolving field.

3.1 SGUS Additive Manufacturing Programme

A key example of AM training is the full-time, nine-month SGUS AM Programme offered by SIMTech in partnership with SSG [36]. This programme focuses on

reskilling and upskilling individuals in AM, covering essential areas such as AM design principles, blown-powder and powder bed fusion processes, post-processing techniques, and quality control procedures for additively manufactured parts. These skills improve employability and address the AM skills gap.

The programme benefits from the WSQ system in several ways, making it appealing to career changers and professionals looking to upskill:

- Modular Structure and Flexibility: The programme leverages a modular structure, allowing trainees to gain relevant skills quickly. This modular format offers additional flexibility—trainees may exit the programme whenever a job opportunity arises. The Graduate Diploma in AM, as detailed in Table 2, is the core of this programme, with five additional modules that broaden participants' expertise. Refer to Table 4 for a complete list of these additional modules.
- Industry-Recognised Credentials: Successful completion of modules equips trainees with the potential to earn certifiable WSQ Statements of Attainments and a Graduate Diploma in AM upon completion of the programme. These credentials are recognised by industry and validate the acquired skills and knowledge, giving graduates an edge in the job market.
- Real-World Experience: The programme concludes with two project modules (Modules 9 & 10), where trainees solve real-world problems alongside potential employers, gaining practical experience and building valuable connections.
- Financial Support: The course fee is heavily subsidized by the government. Trainees may also use their SkillsFuture Credit to further reduce costs. This financial support makes the programme accessible to a broader audience.

Through financial support, industry-focused skills development, and hands-on experience, the SGUS AM programme equips individuals to successfully transition into careers in the evolving field of AM.

Table 4 Additional modules offered under the SGUS AM Programme

Module	Title	Duration (Hours)
6	Data mining for correlation analysis (DM-LITE)	15
7	IIoT-enabled equipment condition monitoring and alert (IECOM)	16
8	Lab-based practice training	120
9	Project-based training for implementation—P1	100
10	Project-based training for implementation—P2	100

3.2 SGUS MedTech Product Manufacturing Programme—AM Module

The SGUS MedTech Product Manufacturing Programme offered by SIMTech incorporates an AM module, acknowledging its growing importance in the medical technology (MedTech) sector. This module equips trainees with AM skills relevant to MedTech applications, preparing them for roles in this field. By integrating AM training, the programme addresses the evolving needs of the MedTech industry, fostering innovation and developing a skilled workforce for advanced medical device manufacturing.

Similar to the SGUS AM programme, this curriculum aligns with the WSQ system, offering trainees industry-recognised skills through WSQ-accredited modules such as "Smart Additive Manufacturing System" and "Understanding Microfluidics Manufacturing Processes." To address the dynamic nature of the MedTech sector, the programme also includes non-WSQ modules that cover emerging trends and specialised topics. For example, "Product Design and Innovation: Molecular Diagnostics (MDx) with Lab-on-a-Chip (LOC)" ensures trainees gain relevant and up-to-date competencies. This combination of WSQ and non-WSQ modules enables the programme to adapt to the specific needs of the MedTech industry.

3.3 Real-World Application: Project-Based Learning and Industry Collaboration

One of the SGUS AM programme's core strengths is its focus on practical application and industry exposure, which complements a solid theoretical foundation. Trainees spend 120 hours in lab-based training and 200 hours on project-based learning, going beyond traditional classroom settings. These activities involve collaboration with research institutes like A*STAR and industry partners on AM projects. This close collaboration strengthens the programme's alignment with industry needs, ensuring graduates acquire relevant skills and knowledge.

The programme adopts a three-pronged approach aligned with SIMTech's Learn-Practice-Implement™ (LPI™) pedagogy [18]:

- Foundation Building: Classroom instruction provides trainees with a comprehensive understanding of AM principles and technologies. This forms the Learn stage of the LPI™ model.
- Skills Development: Hands-on training sessions equip trainees with practical skills in AM processes, equipment operation, and software applications. This represents the Practice stage of LPI™.
- Real-World Application: Project-based learning opportunities serve as the Implement stage of the LPI™ pedagogy. By applying their knowledge and skills to

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real-world projects with industry partners, trainees solidify their understanding and gain practical experience.

This focus on practical application and industry engagement ensures that SGUS AM programme graduates are well-positioned to succeed in the evolving AM landscape.

3.4 SGUS AM Programme Success Stories

The SGUS programmes have a strong track record of equipping mid-career professionals with advanced manufacturing skills essential for success in the Industry 4.0 era [37]. From September 2020 to November 2022, a total of 78 participants enrolled in the SGUS AM and MedTech programmes. Of these, 71 participants completed at least one module, and 42 went on to receive the WSQ Graduate Diploma in Additive Manufacturing, achieving a completion rate of approximately 54%. These graduates are equipped with the knowledge and skills needed to contribute effectively to modern industries. Their achievements showcase the programme's success in addressing the skills gap and preparing participants for careers in advanced manufacturing, particularly in AM.

Graduates of the SGUS AM Programme have secured roles at leading companies. For example, some work as Additive Manufacturing Engineers at GE Aerospace [38], while others hold managerial positions at SIA Engineering Company (SIAEC) [39], where they drive the adoption of AM technologies. These graduates not only utilise AM but also expand its applications in production processes.

The programme's impact extends beyond individual success stories. Past participants collaborate with A*STAR on projects within the Singapore Aerospace Programme (SAP) [40]. This research programme brings together international aerospace companies, A*STAR Research Institutes, Institutes of Higher Learning, and local enterprises to explore areas like AM, robotics, automation, and Internet of Things (IoT). By contributing to these projects, SGUS programme graduates play a role in advancing Singapore's aerospace industry. This collaborative approach highlights the programme's focus on preparing graduates for not just individual career success, but also for industry-wide innovation.

4 Certification and Continuing Professional Development in Additive Manufacturing

Singapore's SkillsFuture movement promotes continuous professional development (CPD). To address the rapid technological advancements in AM, the WSQ system supports ongoing upskilling through flexible learning pathways.

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Bite-sized training modules from accredited providers enable professionals to enhance their expertise in specific AM areas. Topics include machine learning applications in AM, in-situ monitoring and quality control processes, and advanced software for topology optimisation and generative design tailored for AM workflows. This flexible approach ensures that AM professionals stay current with industry trends and maintain their technical proficiency.

Moreover, the modular structure of the WSQ system allows professionals to pursue additional qualifications, progressively expanding their skills and advancing their careers within the AM industry. This collaborative effort between SkillsFuture and the WSQ system enables AM professionals to remain at the forefront of their field and contribute to Singapore's growth in the AM sector.

4.1 Importance of WSQ Certification

In Singapore, WSQ certification is instrumental in establishing workforce credibility. Recognised as a mark of competence and skills, it assures employers that certified individuals possess both the theoretical knowledge and practical expertise necessary for their roles. This endorsement by a trusted national framework provides certified professionals with a competitive edge in the job market.

WSQ qualifications also offer a structured pathway for career advancement. The qualifications align with the Skills Framework, which outlines the skillsets required for various career levels.

For instance, an individual might begin his or her AM journey with a WSQ Certificate in an introductory AM course. This entry-level qualification equips them with a foundational understanding of AM principles and technologies. As they gain experience, they can pursue a WSQ Specialist Diploma in AM, focusing on skills like machine operation, process optimisation, and quality control. This mid-level qualification qualifies them for engineer or specialist roles. Finally, to progress to managerial or leadership positions, individuals can pursue advanced qualifications like the WSQ Graduate Diploma in AM. This programme provides advanced training in areas such as design principles, product and process planning, AM business integration, project management, etc., preparing graduates for supervisory and leadership roles in the AM industry.

In addition to WSQ certifications, SkillsFuture Series (SFS) courses also contribute to workforce development. While both WSQ and SFS courses play significant roles, they serve different purposes and offer distinct benefits.

SFS courses are typically shorter, non-certifiable programmes focusing on emerging skills [41]. They provide valuable exposure to new trends and are ideal for quick upskilling in specific areas but lack the formal recognition of WSQ qualifications.

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Table 5 Learner proficiency levels within the WSQ system

Proficiency level	Description	Course focus
Basic	For learners with limited or no prior knowledge in the subject area	Foundational knowledge and application
Intermediate	For learners with some working knowledge of the subject area	Knowledge and application at a more complex level
Advanced	For experienced practitioners who wish to deepen their skills in the specialised area	Complex and specialised topics

In contrast, WSQ courses require more time and effort from training providers to develop, including course proposal preparation, learning plan creation, and assessment plan development. This rigorous process ensures strict adherence to SSG guidance and approval, ultimately resulting in a nationally recognised credential. Such credential validates a professional's competence and adherence to industry standards, giving them a significant edge in the job market. Employers can be more confident in the skills and knowledge of WSQ-certified individuals, potentially leading to improved career opportunities and earning potential. Additionally, the structured pathway within the WSQ system allows for progressive learning, with qualifications aligned to different proficiency levels (Table 5). This enables individuals to build their skills and qualifications step-by-step, paving the way for career advancement within the AM industry.

While SFS courses offer a quicker introduction to emerging trends, they may not provide the same level of depth or employer recognition. For individuals seeking a long-term career in AM, the investment in time and effort required for WSQ certification can be a strategic decision. The nationally recognised credentials and structured career progression path offered by the WSQ system can significantly enhance their employability and career growth potential in the dynamic field of AM.

Furthermore, the introduction of WSQ Digital Certificates (e-Certs) in November 2014 marked a significant step forward [42]. Replacing hardcopy certificates with secure online versions offers several benefits for both graduates and employers. Employers can easily verify the authenticity of e-Certs through a dedicated online portal, simplifying the hiring process and ensuring they recruit individuals with the appropriate qualifications. This system enhances transparency and builds confidence in the expertise of WSQ-certified AM professionals.

4.2 Examples of WSQ-Accredited Courses for AM

SSG plays a pivotal role in building a skilled AM workforce through its extensive portfolio of WSQ-accredited training programmes. These programmes address diverse learning needs and career aspirations within the AM industry, equipping graduates

with the job-specific competencies sought by employers. Refer to Table 6 for a list of training providers and courses.

The SSG framework adopts a multi-tiered approach to nurturing AM professionals. For professionals aiming to achieve advanced qualifications and a comprehensive understanding of AM principles to lead and innovate, the Graduate Diploma in Additive Manufacturing is a suitable option. Alternatively, professionals seeking in-depth knowledge of specific AM applications can pursue the Specialist Diploma in Precision Engineering (Additive Manufacturing) offered by Nanyang Polytechnic (NYP). This programme equips graduates with a deep understanding of design principles, process selection, and machine operation for various AM technologies, allowing them to specialise in particular areas of the field.

For those seeking a more focused skillset, shorter-duration WSQ-accredited courses are also available. One such course is the "WSQ—Additive Manufacturing and 3D Scanning" course offered by Tertiary Infotech Pte. Ltd. This course equips participants with hands-on experience in technologies like 3D scanning, reverse engineering, and rapid prototyping. Through instruction in digital fabrication, CAD design, and slicing software, graduates gain the necessary skills to contribute effectively to the development of prototypes, custom products, or complex industrial components within the AM workflow.

The enduring relevance and effectiveness of WSQ-accredited AM programmes are maintained through a collaborative approach between government and industry stakeholders. Training providers work closely with the SSG to develop and continually update the curriculum; this ensures that the programmes remain aligned with the latest advancements in AM technology and industry best practices. By incorporating feedback from leading companies and practitioners, the programmes prepare graduates with the skills and knowledge most valued by employers, fostering immediate job readiness upon graduation.

For example, industry feedback might identify a demand for expertise in multi-material AM, 4D printing, or the application of Artificial Intelligence (AI) within the AM workflow. In response to such insights, the curriculum can be adjusted to

Table 6 Selected examples of WSQ-accredited AM training courses

Training provider	Course title	Remarks	Reference
Singapore Institute of Manufacturing Technology (SIMTech)	Modular programmes in additive manufacturing	WSQ graduate diploma	[4]
Nanyang Polytechnic (NYP)	WSQ specialist diploma in precision engineering (additive manufacturing)	WSQ specialist diploma	[5]
Tertiary Infotech Pte. Ltd	WSQ—additive manufacturing and 3d scanning	Training provider is a Singapore-based Small and Medium-sized Enterprise (SME)	[43]

integrate these areas, ensuring that graduates possess in-demand skillsets within the industry.

5 Conclusions

Additive Manufacturing (AM) represents a transformative technology with the potential to revolutionise manufacturing across diverse industries. However, as explored in this chapter, unlocking AM's full potential requires a skilled and adaptable workforce capable of leveraging its capabilities effectively.

This chapter examined the critical role of industry-government collaborative training in empowering the AM workforce, with the Singapore Workforce Skills Qualification (WSQ) system serving as a notable example. By offering clear certification pathways and fostering continuous learning, the WSQ system equips individuals with the skills and knowledge needed by employers, creating a strong foundation for successful careers in the AM industry.

The chapter also acknowledged the challenges faced in this journey, such as the rapid evolution of AM technologies and the need for ongoing adaptation by the workforce. However, the collaborative efforts showcased in Singapore, with strong industry involvement in curriculum development and a focus on continuous reskilling, offer valuable insights for other nations seeking to develop their own AM workforce.

In conclusion, as we move forward, coordinated efforts from industry, government, and educational institutions will remain crucial. By fostering a skilled and adaptable workforce through collaborative training initiatives, clearly defined certification pathways, and continuous reskilling strategies, we can unlock the full potential of AM, driving innovation and shaping a future of manufacturing excellence.

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External Resources: The Singapore Institute of Manufacturing Technology (SIMTech) is dedicated to bolstering Singapore's manufacturing sector. It achieves this by creating cutting-edge manufacturing technologies and nurturing skilled talent. SIMTech collaborates extensively with

both local and international companies in sectors such as Precision Engineering, MedTech, and Aerospace. https://www.a-star.edu.sg/simtech

The Advanced Remanufacturing and Technology Centre (ARTC) is a contemporary platform established through robust public-private partnerships. In partnership with Nanyang Technological University (NTU), Singapore, ARTC maintains a membership consortium comprising over 95 entities, ranging from multinational corporations to small and medium enterprises. ARTC's proficiency in advanced manufacturing and remanufacturing expedites the transition of innovative research into practical industrial applications and solutions, thereby enhancing the capabilities of its industry members across five key sectors: Aerospace, Fast-Moving Consumer Goods and E-commerce, Energy, Land Transport, and MedTech. https://www.a-star.edu.sg/artc

The Knowledge Transfer Office (KTO), a collaborative effort between SIMTech and ARTC, is a leader in advanced manufacturing workforce training. Leveraging the combined expertise and resources of both institutes, KTO is committed to providing comprehensive and impactful training programmes that equip the workforce with the skills needed to drive Singapore's manufacturing industry forward. https://www.a-star.edu.sg/simtech/kto/mainpage

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Page no	Fig/Photo	Thumbnail	Alt-text Description
2	Fig1		Flow chart illustrating the progression of WSQ levels from Level 1 to Level 6. Each level is represented by a box with an upward arrow indicating advancement. The levels are: WSQ Level 1 – Certificate, WSQ Level 2 – Higher Certificate, WSQ Level 3 – Advanced Certificate, WSQ Level 4 – Diploma, WSQ Level 5 – Specialist Diploma, and WSQ Level 6 – Graduate Diploma.