Tested and Refined Curriculum for Beyond 5G Digital and Green Industrial Technologies

5G-DiGITs

Cross-sectorial education and talent development for beyond 5G Digital and Green Industrial Technologies.

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Abbreviations

Abbreviation	Description
2G	Second Generation Mobile Networks
3G	Third Generation Mobile Networks
4G	Fourth Generation Mobile Networks
5G	Fifth Generation Mobile Networks
6G	Sixth Generation Mobile Networks (future)
AI	Artificial Intelligence
API	Application Programming Interface
B5G	Beyond 5G
CN	Core Network
EACEA	European Education and Culture Executive Agency
ECTS	European Credit Transfer and Accumulation System
EQF	European Qualifications Framework
ERASMUS+	European Union Programme for Education, Training, Youth and Sport
EU	European Union
ICT	Information and Communication Technologies
IoT	Internet of Things
KPI	Key Performance Indicator
KSA	Knowledge, Skills, and Abilities
LMS	Learning Management System
LCA	Life Cycle Assessment
LO	Learning Outcome
MCQ	Multiple Choice Question
MEC	Multi-access Edge Computing
MIMO	Multiple Input Multiple Output
ML	Machine Learning
mmWave	Millimetre Wave
mMTC	Massive Machine-Type Communications
NFV	Network Functions Virtualization
NR	New Radio

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PBL	Problem-Based Learning
PU	Public (Dissemination Level)
QoS	Quality of Service
RAN	Radio Access Network
SBA	Service-Based Architecture
SDN	Software-Defined Networking
SME	Small and Medium-sized Enterprise
UE	User Equipment
UDL	Universal Design for Learning
URLLC	Ultra-Reliable Low Latency Communication
WP	Work Package (in project context)

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Executive Summary

Deliverable **D2.6 – Tested and Refined Curriculum for Beyond 5G Digital and Green Industrial Technologies –** presents the results of the pilot implementation, evaluation, and refinement of the modular curriculum developed within the 5G-DiGITs project. It represents a key step in Work Package 2, moving the curriculum from its design phase to its validation in real learning environments.

Building upon the structured curriculum introduced in Deliverable D2.2, this deliverable documents how the eight courses were delivered during the pilot phase, how learners engaged with the materials, and how feedback from participants and instructors informed targeted improvements.

The pilot implementation aimed to assess the curriculum's pedagogical effectiveness, workload balance, relevance to learner needs, and alignment with the project's broader objective of supporting Europe's digital and green transitions. Through a combination of learner feedback, instructor observations, and implementation experience, the project partners identified strengths, challenges, and opportunities for refinement across the course portfolio.

For each course, the deliverable reports on the actual delivery approach, the responses gathered from participating learners, and the adjustments introduced to improve clarity, structure, and learning impact. In addition to individual course analysis, the document synthesises cross-course insights, highlighting common patterns and lessons learned that inform the future evolution of the curriculum.

Overall, D2.6 demonstrates that the 5G-DiGITs curriculum has progressed from a planned educational framework to a tested and refined learning offer. The findings presented in this deliverable confirm the curriculum's relevance, adaptability, and potential for wider adoption across higher education, vocational training, and professional upskilling contexts in Europe.

The outcomes of this phase provide a solid foundation for the continued deployment, dissemination, and long-term sustainability of the 5G-DiGITs educational framework.

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1. Introduction

1.1. Purpose of the Deliverable

Deliverable **D2.6 - Tested and Refined Curriculum for Beyond 5G Digital and Green Industrial Technologies -** presents the results of the pilot implementation, evaluation, and refinement of the modular curriculum developed within the 5G-DiGITs project.

While Deliverable D2.2 defined the curriculum structure, course design, and learning materials, this deliverable focuses on the pilot testing and validation of the curriculum in practice, documenting how the courses were delivered, how they were perceived by learners, and how they were subsequently improved.

The main objective of D2.6 is to demonstrate the transition from a designed curriculum to a tested, evaluated, and refined educational framework, ensuring that the learning offered is pedagogically effective, learner-centred, workload-balanced, learner-engaging, and aligned with the evolving needs of the digital and green transition sectors.

1.2. Relation to Previous Deliverables

This deliverable builds upon the earlier outputs of Work Package 2:

- **D2.1 - Needs Assessment Report**, which identified key skills gaps and training priorities in the Beyond 5G ecosystem
- **D2.2 - Modular Curriculum Structure and Learning Materials**, which translated these needs into a structured curriculum composed of eight modular courses
- **D2.3 - Real-World Problems and Case Studies**, which introduced the PBL-oriented case studies integrated into the curriculum that D2.6 evaluates

D2.6 represents the next step in the curriculum lifecycle. It documents the experience gained during the pilot delivery of the courses and illustrates how stakeholder feedback and instructional insights were incorporated to improve course content, teaching approaches, and overall learning effectiveness.

The document is not just a feedback report; it is the culmination of the curriculum development chain. It:

- validates the curriculum in implementation
- reports evidence from pilot delivery
- documents curriculum refinements at the course and package level

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1.3. Scope of the Deliverable

This deliverable covers the **pilot implementation**, **evaluation**, and refinement of the eight courses developed within the 5G-DiGITs curriculum framework. It documents how each course was delivered during the pilot phase, the feedback collected from participating learners, and the adjustments introduced in order to improve clarity, relevance, pedagogical effectiveness, and the overall learning experience. For each course, the deliverable presents a structured account of the implementation process, the main findings arising from learner feedback and course evaluation, and the resulting **refinements** applied to strengthen the course design, delivery, and educational value. In this respect, the document captures both the practical deployment of the curriculum in the project's digital learning environment and the evidence-based revision process undertaken following pilot testing.

Beyond the individual course reports, the deliverable provides a **cross-course analysis** to identify common strengths, recurring challenges, and shared opportunities for improvement across the curriculum portfolio. This comparative perspective supports an assessment of the curriculum's overall coherence, adaptability, and transferability across different learning contexts and target groups. Taken together, the deliverable offers a consolidated view of the curriculum's maturity and **readiness for wider deployment**. As such, it serves not only as a record of pilot implementation but also as a presentation of the curriculum in its refined form, reflecting the improvements introduced through testing, evaluation, and revision.

1.4. Structure of the Deliverable

The remainder of this deliverable is organised as follows. **Section 2** sets out the methodological framework underpinning the **pilot testing**, **evaluation**, and **curriculum refinement** process. It describes the scope of the pilot phase, the digital learning environment in which the courses were delivered, the participant profile, the instruments used for data collection, the evaluation dimensions applied, and the procedure used to analyse and translate the findings into course-level improvements.

Section 3 constitutes the main body of the deliverable and presents the results of the pilot implementation on a course-by-course basis. For each of the eight courses, it provides a structured account of the implementation approach, the feedback collected from participating learners, and the refinement actions introduced in response to the evaluation outcomes.

Section 4 provides a cross-course synthesis of the main findings emerging from the pilot phase. It highlights common patterns, pedagogical insights, technical and delivery-related lessons learned, and the extent to which the refined curriculum responds to the broader objectives of the project.

Section 5 concludes the deliverable by summarising the pilot phase's overall outcomes and reflecting on the curriculum's maturity, coherence, and readiness for wider deployment. The document is complemented by the relevant references and, where appropriate, annexed supporting material.

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2. Methodology for Pilot Testing, Evaluation, and Curriculum Refinement

2.1. Purpose and Scope of the Pilot Phase

The pilot phase served as the validation stage of the 5G-DiGITs curriculum, following the design and development work completed in Deliverable D2.2. Its purpose was to implement the newly developed courses in a real digital learning environment and to assess how effectively the curriculum functioned in practice, focusing on pedagogical clarity, workload balance, learner relevance, engagement, and overall usability. In this respect, the pilot was conceived not as a standalone activity, but as the evidence-generating phase required to support the final refinement of the curriculum.

The scope of the pilot covered all eight courses developed within the project and focused on the practical delivery of the curriculum in Moodle-based course spaces, the collection of learner feedback and implementation evidence, and the identification of necessary improvements at the course and module levels. Particular attention was given to the extent to which the implemented courses reflected the intended modular design, supported flexible learning pathways, and enabled the use of applied learning approaches, including problem-based learning where relevant.

In line with Task T2.4, the pilot phase was also intended to support a structured review of student engagement, learning outcomes, and participant feedback in order to identify strengths, gaps, and areas requiring adjustment. The findings generated during this phase, therefore, provided the basis for the refinement actions documented later in this deliverable and contributed to the consolidation of the curriculum in its tested and improved form.

2.2. Pilot Setting and Delivery Environment

The pilot phase was conducted in the project's **digital learning environment**, using a Moodle-based platform as the common Learning Management System (LMS) for implementing the 5G-DiGITs curriculum. This platform provided the shared infrastructure through which the eight courses were deployed, accessed by learners, and monitored by the participating institutions during the pilot period. The use of a common LMS ensured a consistent digital setting for course delivery while also allowing each course space to reflect its specific content, pedagogical design, and assessment logic.

Within this environment, the curriculum was implemented through **structured online course spaces** organised around modules, units, and lesson-level sections. In line with the modular design established in D2.2, the courses combined different types of digital learning resources, including recorded or narrated presentations, presentation slides, and supporting materials, references for further study, self-evaluation activities, and, where applicable, problem-based learning tasks and deliverables. This structure enabled asynchronous learning, flexible progression through the content, and a consistent learner experience across different courses and institutions.

The Moodle environment also served as the operational setting for the pilot implementation itself. It enabled learners to access the learning materials, complete quizzes and assignments, participate in course activities, and submit practical deliverables linked to course tasks or case studies. At the same time, it provided instructors and partner institutions with a common framework for supervising learners, observing participation, and collecting evidence of implementation during the pilot phase. In this sense, the digital environment was not only the

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medium of delivery but also the context in which the curriculum's usability, pedagogical coherence, and practical feasibility were tested.

Particular importance was attached to the fact that the pilot did not assess the curriculum only as a set of static course materials, but as an **implemented online learning offer**. The delivery environment, therefore, formed an integral part of the evaluation methodology, since issues such as course structure, navigation, accessibility of learning resources, balance between theoretical and applied components, and the suitability of digital assessment tools could only be meaningfully examined in an actual LMS-based setting. This also justifies the inclusion of course implementation details in Section 3 of the present deliverable, where the digital instantiation of each course is documented before the feedback and refinement stages are reported.

2.3. Participants and Pilot Sample

The pilot phase was carried out in the project's shared Moodle-based learning environment, where all eight 5G-DiGITs courses were made available to learners from the four participating HEIs. Each HEI selected and enrolled a locally supervised group of learners into all pilot courses, ensured that they received access credentials and introductory guidance, and monitored their participation throughout the pilot period. In practice, this meant that students were registered in the relevant Moodle course spaces, followed the structured sequence of modules and units, completed quizzes and self-evaluation activities, and, where applicable, undertook problem-based learning tasks and submitted short assignments. The pilot was initially planned to involve at least 40 participants across the consortium, with each HEI contributing approximately 10 learners. Through broad internal dissemination within the institutions, the project ultimately enrolled 88 registered learners with diverse educational levels and backgrounds. After registration on the platform, local instructors provided detailed guidance and allowed learners a minimum of two weeks to navigate the course spaces before completing the course-specific questionnaires presented in Annex II. During this period, instructors closely monitored learner activity and responded to any questions; in the case of KAU, they were also able to organise face-to-face evaluation sessions as part of ongoing local activities, collecting additional comments and impressions through direct interaction. This asynchronous implementation model was selected because i) it reflects realistic conditions in which learners access online materials at their own pace and availability, and ii) the academic calendars, teaching schedules, and examination periods of the participating HEIs could not be fully synchronised.

The participants profile reflected the broader target groups of the project and of the curriculum itself. The pilot primarily addressed higher-education learners in ICT, engineering, and related technological domains, including Bachelor, Master, and PhD students who were able to follow the technical depth of the courses. At the same time, the pilot remained open to early-career professionals and other learners seeking to strengthen their competences in advanced 5G, digital, green, and entrepreneurial skills, particularly in courses with a stronger transversal or innovation-oriented focus. Methodologically, the pilot sample was conceived as a purposive, practice-oriented sample rather than a statistically representative population: its role was to generate implementation-based evidence on how the courses operated in authentic institutional settings, how different learner profiles engaged with the modular structure and workload, and which aspects of course design and delivery required refinement before wider rollout.

From a methodological perspective, the pilot sample was therefore conceived as a **purposive, practice-oriented sample rather than** a statistically representative population. Its role was to provide direct evidence on how the courses functioned in authentic learning contexts, how learners engaged with the materials, and which aspects of course structure, workload, clarity, or applied activities required refinement. The value of the sample for the purposes of D2.6 lies in its capacity to generate implementation-based feedback across different courses and institutions, rather than in enabling broad generalisation beyond the project context.

2.4. Data Collection Instruments and Evidence Sources

The pilot evaluation was based on a combination of **learner feedback**, **implementation-related observations**, and **evidence generated through the digital learning environment**. This mixed-methods evidence base was considered necessary to assess not only participants' perceptions of the courses but also the practical functioning of the curriculum in an implemented online setting. The intention was therefore to gather information that could inform both the pedagogical evaluation of the courses and the identification of concrete refinement needs.

A central data-collection instrument was an online feedback questionnaire administered to participating learners after their engagement with the course materials. These instruments were designed to capture learners' views on aspects such as **initial knowledge level**, **knowledge and skills improvement**, **relevance of the content**, **fit to learner profile**, **course structure and organization**, **clarity and consistency**, **alignment between learning outcomes, materials, and assessments**, **engagement and satisfaction**, **quality of learning materials**, **pedagogical approach**, and, where applicable, the **usefulness of problem-based learning activities**. In addition to closed or structured responses, the feedback process also allowed open comments, enabling participants to identify specific strengths, difficulties, or suggestions for improvement related to particular modules, units, or learning activities [Nia].

The pilot evaluation also drew on **implementation evidence** generated during course delivery in the Moodle environment. This included information on the organisation of course spaces, the availability and accessibility of learning resources, the completion of self-evaluation activities, the use of quizzes, and the submission of practical tasks or case-study deliverables where applicable. Although these elements were not treated as formal learning analytics in a strict quantitative sense, they provided useful indications regarding learner interaction with the course structure and the practical feasibility of the implemented learning pathway.

A further source of evidence consisted of **partner and instructor observations** emerging from the local supervision of learners during the pilot phase. Since each participating institution was responsible for guiding and monitoring its own pilot participants, partners were also able to identify recurring questions, organisational issues, points requiring clarification, or implementation-related challenges. These observations complemented the learner questionnaires by adding a practice-based perspective on how the courses operated in real conditions.

Taken together, these data collection instruments and evidence sources were used to support a **course-level and cross-course review** of the curriculum. Their role was not only to register learner satisfaction, but also to provide a sufficiently broad evidence base for the analysis of engagement, learning experience, usability, and refinement needs addressed in the following subsections and in the course reports presented in Section 3 [Rajabalee].

The learner feedback questionnaire used during the pilot phase is provided in **Annex 1** as a supporting evaluation instrument.

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2.5. Evaluation Dimensions and Success Criteria

The pilot evaluation was structured around a set of common **evaluation dimensions** intended to assess how effectively the implemented courses functioned in practice. These dimensions were defined to ensure that the pilot phase review went beyond general satisfaction and addressed the aspects most relevant to refining the curriculum. In line with the objectives of Task T2.4, the evaluation focused on **student engagement**, **learning outcomes**, and **participant feedback**, while also assessing **course organization**, **quality of learning materials**, **pedagogical approach**, **digital learning experience**, and the suitability of **applied and problem-based learning activities**, as reflected in the learner questionnaire included in **Annex 1.**

The first dimension concerned **learner engagement**. This referred to the extent to which participants were able to progress through the implemented course structure, access the different learning resources, complete quizzes or practical tasks, and interact meaningfully with the proposed learning pathway. In the context of the pilot, engagement was considered an important indicator of whether the modular organisation of the courses, the balance between lesson components, and the design of the Moodle environment supported sustained participation and manageable progression through the materials.

The second dimension concerned **learning effectiveness and perceived achievement of intended outcomes**. This dimension was also reflected in the learner questionnaire through items related to **initial self-assessment** and **perceived improvement in knowledge and skills.** Given the pilot-oriented nature of the implementation, this dimension was examined primarily through the quality of learner responses, self-evaluation activities, and the overall coherence between course content, learning tasks, and expected competences. Particular attention was paid to whether the courses enabled learners to understand the target concepts, apply them in relevant tasks or case-based activities, and perceive the content as meaningful for their academic or professional development. In this respect, the evaluation did not rely solely on formal testing but also on broader alignment between course design, learner understanding, and applied learning opportunities.

A third dimension related to **course quality and learner experience**. This included the clarity of the course structure, the comprehensibility of the learning materials, the adequacy of the workload, the accessibility and usability of the resources, and the perceived relevance of the content to learner needs and expectations. Since the curriculum was delivered in a digital environment and intended to support flexible online participation, this dimension was particularly important for assessing whether the implemented courses were sufficiently coherent, navigable, and user-oriented.

A fourth dimension addressed the **suitability of assessment and problem-based learning components**. As several courses incorporated self-evaluation quizzes, applied tasks, and case-study activities, the pilot also examined whether these components were appropriately integrated into the learning pathway, whether they supported understanding and application of the course content, and whether they contributed meaningfully to the overall educational value of the curriculum. This dimension was especially relevant for assessing the courses' practical orientation and the effectiveness of the pedagogical approaches used.

Taken together, these dimensions provided the basis for identifying both **strengths** and **areas requiring refinement**. A pilot implementation was considered successful where it demonstrated a coherent course structure, manageable workload, meaningful learner engagement, perceived learning value, and appropriate use of digital and applied learning components. Conversely, issues affecting clarity, balance, usability, or pedagogical effectiveness were treated as signals requiring review and, where necessary, refinement in the subsequent stages documented in this deliverable.

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2.6. Procedure for Analysis and Interpretation

The evidence collected during the pilot phase was analysed through a **course-level review process** to identify both the strengths of the implemented curriculum and aspects requiring refinement. Given the nature of the pilot and the size of the participant groups, the analysis was primarily interpretative and practice-oriented, focusing on identifying meaningful patterns in learner feedback, implementation observations, and course-delivery evidence rather than on complex statistical analysis. The purpose of the analysis was therefore to support curriculum improvement by structuring the reading of data generated during the pilot implementation.

At the course level, the available evidence was reviewed in relation to the main evaluation dimensions defined in the previous subsection: learner engagement, perceived learning effectiveness, course quality, learner experience, and the suitability of the assessment and problem-based learning components. Responses from learner questionnaires, open comments, evidence of activity completion, and observations made during local supervision were examined together to identify recurring issues, consistent positive features, and specific implementation challenges for each course and module.

The interpretation of findings followed a comparative logic. First, the information available for each course was considered internally, with attention to the relationship between course structure, workload, digital learning resources, and the nature of the feedback received. Second, common themes emerging across multiple courses were identified in order to detect cross-cutting patterns affecting the curriculum as a whole. This made it possible to distinguish between issues that were course-specific and those that reflected broader pedagogical or organisational considerations relevant to the portfolio of courses.

Where recurring comments or observations pointed to the need for change, these were translated into **actionable refinement themes**. Such themes included, for example, rebalancing the workload, clarifying specific explanations, improving navigation or sequencing in the digital environment, strengthening alignment between theory and practical activities, or adjusting the design of quizzes and applied tasks. The analysis, therefore, functioned not only as a descriptive account of the pilot but as a mechanism for linking evidence to revision priorities.

Methodologically, the interpretation of the pilot findings should be understood as an evidence-informed review rather than a formal impact assessment. Its value lies in systematically using available pilot evidence to inform course and curriculum refinement. The resulting analytical logic provides the basis for the refinement actions presented later in this deliverable, at both the individual-course and the curriculum-as-a-whole levels.

2.7. Curriculum Revision and Decision-Making Process

The curriculum revision process was directly informed by the findings emerging from the pilot phase. Once the available evidence had been reviewed and interpreted, the identified strengths and weaknesses of the implemented courses were translated into potential improvement actions at the course, module, and activity levels. In this way, the revision process ensured that refinements were grounded in pilot experience rather than introduced ad hoc.

The decision-making logic for curriculum refinement was guided by a combination of pedagogical relevance, practical feasibility, and consistency with the original curriculum framework established in D2.2. This meant that not every isolated comment automatically resulted in a change. Instead, priority was given to adjustments that addressed recurring feedback, clearly identified usability or workload issues, improved the clarity and sequencing of

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content, strengthened the alignment between learning outcomes and course activities, or enhanced the practical value of the learning experience. Where applicable, attention was also given to the integration and effectiveness of problem-based learning tasks and self-evaluation components.

The revision process could therefore affect different elements of the implemented courses. Depending on the nature of the issue identified, refinements might relate to the wording and organisation of syllabus components, the sequencing of lessons and units, the clarity or depth of the learning materials, the balance between theoretical and applied content, the design of quizzes and practical exercises, the workload distribution across units, or the usability of the Moodle course structure. This broad scope of possible adjustments reflects the fact that the pilot was intended to assess the curriculum as an implemented learning offer rather than only as a static set of materials.

At the same time, the revision process sought to preserve the overall coherence of the curriculum and its modular structure across the eight courses. Refinements were therefore considered not only in relation to individual course issues but also to the broader objectives of the 5G-DiGITs curriculum, including flexibility, interdisciplinary relevance, digital accessibility, and the integration of applied learning approaches. This ensured that local or course-specific improvements could be incorporated without undermining the curriculum framework's common logic.

The refinement actions resulting from this process are reported in Section 3, course-by-course, and later synthesised in Section 4 at the curriculum level. In this sense, the revision and decision-making process constitutes the methodological bridge between the analysis of pilot findings and the consolidation of the curriculum in its refined form.

2.8. Consolidation of the Final Curriculum Package

The pilot testing, evaluation, and revision process described in the previous subsections was intended not only to generate findings on course implementation but also to support the consolidation of the curriculum in its final, **refined form**. In this respect, D2.6 should be understood as more than a pilot report: it serves as the deliverable through which the results of pilot implementation are translated into an updated and validated curriculum package. This function is explicitly consistent with the role assigned to D2.6 in the project proposal, where the deliverable is defined as the final version of the curriculum, refined on the basis of feedback and pilot evidence.

The consolidation of the final curriculum package therefore involves revisions to various curriculum components based on the results of the pilot phase. These include updates to **syllabi**, **lesson sequencing**, **learning materials**, **assessment and self-evaluation components**, and **problem-based learning activities** or their associated guidance. Where needed, refinements also affect the way content is structured in the Moodle environment, the balance of workload across units, and the presentation of resources intended to support learner progression and accessibility. This reflects the fact that the curriculum is being consolidated not only as a set of documents, but also as an implemented, pedagogically tested learning offer.

In this deliverable, this consolidation is reflected in the course-level reporting in **Section 3**, where implementation evidence, available feedback, and resulting refinement actions are documented for each course. In addition, where appropriate, supporting materials are included in the annexes in order to capture specific elements of the final package more explicitly, such as **evaluation instruments**, revised summaries, updated activity descriptions, or course-specific revision records. This approach allows the main body of the deliverable to remain focused and

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analytical while ensuring that the refined curriculum is documented in a usable, traceable format.

This consolidation step is methodologically important because it closes the loop between **curriculum design**, **pilot implementation**, **evaluation**, and **refinement**. It demonstrates that the pilot phase led to tangible curriculum improvements and that the final outputs of Work Package 2 extend beyond initial course design to include a revised curriculum package capable of supporting continued use, adaptation, and wider deployment across different educational contexts. In this way, D2.6 contributes to the overall continuity of the WP2 deliverables, building on the modular structure and learning materials developed in D2.2 and incorporating the applied learning dimension supported through the project's PBL-oriented work.

2.9. Methodological Limitations

The methodological approach adopted for the pilot phase provided a useful basis for evaluating the implemented courses and identifying areas for refinement. At the same time, the interpretation of the findings should be considered in light of several limitations inherent to the pilot design and the stage at which the analysis was conducted. Acknowledging these limitations is important for situating the findings appropriately and ensuring a transparent reading of the evidence presented in this deliverable.

First, the pilot was based on a **practice-oriented, relatively small-scale participant sample** distributed across partner institutions and courses. While this design was appropriate for testing the functionality and pedagogical value of the curriculum in authentic educational settings, it does not support broad statistical generalisation. The value of the pilot lies primarily in its capacity to generate targeted implementation evidence, learner feedback, and course-level insights that can inform curriculum refinement.

Second, the pilot implementation took place across different institutional contexts, with some variation in local supervision, timing, course uptake, and the maturity of implementation across the course portfolio. As a result, the quantity and level of detail of the available evidence may not be fully uniform across all courses and modules. This should be taken into account when comparing pilot outcomes across the full curriculum and when interpreting cross-course patterns.

In addition, the evaluation relied on a combination of learner questionnaires, implementation observations, and course-delivery evidence rather than on a fully standardised experimental design or formal impact assessment methodology. This means that the findings are best understood as **evidence-informed judgments** on curriculum performance, usability, and refinement needs, rather than as definitive measurements of long-term learning impact. Nevertheless, this approach remains appropriate for D2.6, whose primary objective is to document the pilot implementation and support curriculum improvement.

Despite these limitations, the pilot methodology provides a sufficiently robust basis for identifying meaningful strengths, recurring issues, and actionable refinement priorities across the implemented courses. The limitations identified here do not invalidate the findings, but rather define the interpretative boundaries within which they should be understood and used in the consolidation of the final curriculum package.

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3. Course Implementation Reports

This section presents the implementation of the courses developed within the 5G-DiGITs curriculum during the pilot phase. For each course, the section describes how the learning content was organised and delivered through the project's online learning environment, as well as the pedagogical approach adopted for the development of the learning materials.

More specifically, the following subsections provide an overview of the structure of each course, including the modules and units that compose the learning pathway, as well as the instructional components used throughout the courses. These components include video lectures, transcripts, self-evaluation quizzes, home exercises, downloadable learning materials, and final assessments designed to support knowledge consolidation.

The purpose of this section is to document the way in which the designed curriculum was implemented in practice and to provide a clear overview of the learning structure and educational resources developed for each course [Douglas].

3.1. Introduction to Advanced 5G Technologies

3.1.1. Course Implementation

Characteristics	Description
Course title	Introduction to Advanced 5G Technologies
Duration	60 hours (2 ECTS)
Delivery mode	Online asynchronous course via Moodle LMS
Course structure	3 Modules – 6 Units
Learning Format	Video lectures, transcripts, quizzes, exercises, downloadable materials
Assessment	Self-evaluation quizzes and final assessment
Learning approach	Self-paced learning with structured unit progression

Table 1. Course details of Introduction to Advanced 5G Technologies

The course Introduction to Advanced 5G Technologies was developed as an introductory module within the 5G-DiGITs curriculum to provide learners with a structured understanding of the technological foundations, architecture, applications, and future development of advanced mobile communication systems. The course corresponds to 2 ECTS credits, representing an estimated student workload of approximately 60 hours, including study of the learning materials, completion of quizzes and exercises, and participation in the final assessment.

The course content is delivered through the project's online learning environment hosted on the Moodle learning management system (LMS), an open-source digital platform widely used in higher education to support online and blended learning. Through this platform, learners are able to access the course materials, including recorded video lectures, transcripts, quizzes, and additional learning resources, and follow the course in a structured and self-paced manner.

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In line with the curriculum framework defined in Deliverable D2.2, the course targets learners in ICT, telecommunications, and engineering-related fields, including students at Bachelor's, Master's, and PhD level, as well as early-career professionals interested in developing foundational competences in advanced mobile networking technologies.

The course was organised into three thematic modules, each consisting of two units, designed to guide learners progressively from the historical evolution of mobile communications to the technological foundations of 5G networks and their emerging applications and future trends.

Module 1 – Evolution of Mobile Communications and Fundamentals of 5G

The first module provides the historical and conceptual background required to understand the emergence of modern mobile communication systems. It introduces the technological evolution of mobile networks and highlights the key innovations that led to the development of 5G technologies.

Unit 1.1 – Mobile Networks Evolution Towards 5G

This unit introduces the basic principles of mobile networking and traces the historical evolution of mobile communication systems. The learning content is organised into several sections covering mobile networking fundamentals, the development of early mobile communication generations, and the **technological** progression from 1G and 2G to 3G, 4G, and eventually 5G systems. Additional sections examine performance improvements across different mobile generations and introduce the role of standardisation processes in the development of mobile communication technologies.

Unit 1.2 – Introduction to 5G and 5G Advanced Systems

Building on the historical perspective introduced in the previous unit, Unit 1.2 focuses on the fundamental characteristics and design principles of 5G systems. The unit introduces the main components of 5G architectures, explains their functional roles within the network ecosystem, and presents the key technological concepts supporting the design and operation of modern 5G infrastructures. Particular attention is given to the defining features of 5G systems and the technological innovations that distinguish them from earlier generations of mobile communication technologies.

Module 2 – Enabling Technologies at the 5G Access and Core Networks

The second module focuses on the technological foundations that enable the operation and performance of modern 5G networks. It examines both the radio access network and the core network components that together form the overall 5G system architecture.

Unit 2.1 – Enabling Technologies at the 5G Access Network

This unit examines the key technologies supporting the radio access network of 5G systems. It introduces the main radio technologies used in the 5G New Radio (NR) interface and explains their functional role in enabling high-performance wireless communication. The unit also presents advanced technologies such as Massive MIMO and discusses architectural concepts such as functional split within the radio access network. These technological developments enable improved radio performance and support new communication services with demanding performance requirements.

Unit 2.2 – Enabling Technologies at the 5G Network Core

The second unit of this module focuses on the architecture and functionality of the 5G core network. It introduces the main technologies and protocols used within the 5G core and explains how they support network flexibility, scalability, and advanced service delivery. The unit also examines the internal structure of the core network, including its functional components and

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operational mechanisms. Additional sections discuss how the 5G core architecture supports advanced network performance and enables the provision of new digital services and network capabilities.

Module 3 – 5G Applications, Vertical Challenges and Future Trends

The third module shifts the focus from technological infrastructure to the practical application of 5G systems and their broader technological implications. It explores how advanced connectivity enables new services and how mobile communication technologies are expected to evolve in the future.

Unit 3.1 – 5G Applications and Use Cases

This unit explores the range of new applications enabled by 5G technologies and examines how these systems support emerging digital services. The sections introduce different 5G use cases and analyse practical deployment scenarios in which advanced connectivity plays a central role. Particular attention is given to the role of 5G in vertical industries, including sectors where high-capacity, low-latency communication infrastructure is required to support digital transformation and smart service ecosystems.

Unit 3.2 – Challenges and Future Trends

The final unit examines the limitations and challenges associated with current 5G technologies while introducing emerging research directions and future developments in mobile communications. The unit discusses technological constraints in existing systems, ongoing research efforts aimed at addressing these challenges, and standardisation activities related to future network generations. It also introduces the technological and business trends associated with the transition from 5G to Beyond-5G and early 6G developments.

Pedagogical Structure and Learning Resources

Across all modules and units, the course followed a consistent pedagogical structure within the Moodle learning environment. Each lesson typically included a recorded video lecture explaining the main concepts, accompanied by presentation slides with speaker notes provided as transcript-style support material, enabling learners to follow the content either through video-based instruction or through reading-based study. This dual format was intended to enhance accessibility and support different learning preferences.

To reinforce understanding and promote active learning, each lesson included self-evaluation quizzes designed as formative assessment tools. These quizzes allowed learners to immediately verify their comprehension of the concepts presented in the lesson and to identify areas that might require further review. In many cases, these quizzes also provided immediate feedback, helping learners consolidate key knowledge before progressing to the next section.

In addition to the core lesson components, each unit included home exercises, encouraging learners to reflect on the material and apply the knowledge acquired during the lessons. Learners were also provided with downloadable supporting materials, which included additional references and supplementary learning resources intended to deepen their understanding of the topics covered in each unit.

At the end of each unit, learners were presented with a summary section highlighting key takeaways and learning outcomes, allowing them to revisit the most important concepts and review the competencies developed during the unit. This structure supported self-paced learning and helped ensure that learners could easily navigate the content while maintaining a clear overview of their learning progress.

The course concluded with a final assessment, designed to consolidate the knowledge and understanding developed throughout the modules. The final assessment provided learners with

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the opportunity to evaluate their overall comprehension of advanced 5G technologies and to integrate the theoretical and applied perspectives introduced across the course.

Overall, the implemented course provides a structured learning pathway that combines theoretical explanations, technological analysis, and application-oriented perspectives on advanced mobile communication systems.

3.1.2. Feedback and Observations

This report is based on a total of 33 responses collected through a course evaluation survey. The questionnaire combines quantitative ratings, based on scale-type questions, with open-ended responses that provide qualitative feedback from participants.

Overall, this course stands out for exhibiting the highest variability of opinions among those analyzed. While a significant proportion of students perceive it as useful and generally well organized, a number of recurring issues negatively affect the learning experience. These include weaknesses in the internal structuring of the content, an excessive amount of material per unit, overly long video lectures, extensive use of synthetic voice narration, and a noticeable lack of practical examples and guided reinforcement.

Regarding the quantitative results, there is a clear predominance of medium-to-high ratings, with most items scoring between 3 and 5. Several excellent ratings are also observed, particularly from participants with a strong technical background. However, there are also clusters of very low ratings (between 1 and 2), especially among Master’s students, who report greater difficulties in understanding the material or a lack of clarity in certain sections.

The dispersion of results varies significantly depending on the student profile. PhD candidates with a background in 5G tend to provide positive evaluations, although they point out issues such as content repetition and insufficient depth in advanced topics. In contrast, PhD students from non-technical fields, such as social sciences or business, often consider the course less suited to their needs. Master’s students represent the most divided group in their assessments, while Bachelor’s students generally report above-average levels of satisfaction.

Among the most highly rated aspects are the overall organization of the course and the coherence between its units, as well as the clarity of terminology in most sections. Students also recognize the relevance of the technical content, particularly in areas such as 5G/5G-A, RAN, core networks, network slicing, and edge computing. Quizzes are generally perceived as useful, and complementary materials—such as PDFs, transcripts, and slides—are considered supportive when properly aligned with the course content. Additionally, some students appreciate the use of visual representations.

Nevertheless, several areas for improvement have been identified. The internal structure of the units is sometimes perceived as unclear due to the coexistence of multiple elements—videos, quizzes, assignments, and additional resources—without sufficient organization. The excessive length of videos leads to loss of attention and, in some cases, poor alignment with the accompanying slides. Furthermore, the intensive use of AI-generated voice is described as monotonous and tiring, negatively impacting student engagement. Other issues include repetition of graphics and explanations, a lack of applied exercises, inconsistencies in quizzes, and an overall high density of information.

From a qualitative perspective, the course demonstrates clear strengths, such as comprehensive coverage of key 5G concepts, a generally sound macro-organization, and the usefulness of quizzes. The supporting materials can enhance learning when properly aligned with the content. However, notable weaknesses persist, including the monotony of the AI-generated narration,

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navigation difficulties, excessively long videos, suboptimal structuring of materials, repetition, and a level of content that may be too basic for more advanced learners.

3.1.3. Refinements and Adjustments

Based on the analysis of learner feedback and pilot implementation observations, a set of targeted refinement actions has been defined to enhance the pedagogical effectiveness, usability, and overall learning experience of the course “Introduction to Advanced 5G Technologies”. These refinements focus on improving content delivery, learner engagement, structural clarity, and alignment between learning materials and assessment components, while preserving the overall structure and scope of the course.

A first refinement line concerns **optimisation of video lectures and content delivery**. In response to feedback highlighting reduced engagement with long video lectures and the limitations of AI-generated narration, selected video content will be restructured into shorter and more focused segments. This adjustment aims to improve attention, pacing, and overall learner engagement. In addition, where feasible, AI-generated voice will be replaced or complemented by human narration in order to create a more natural and less monotonous learning experience. Minor revisions in content sequencing and section titles will also be introduced to improve the logical flow and clarity of the learning pathway. These refinements are reflected in the revised course syllabus through the updated description of learning materials and video delivery format.

A second refinement line involves the **improvement of internal structure and navigation of learning units**. To address issues related to the organisation of content within units, the internal structure of learning materials will be refined by establishing a clearer and more consistent sequence of learning elements (e.g., video lecture → supporting material → quiz → exercise). This restructuring aims to improve navigation within the LMS environment, reduce learner confusion, and support a more intuitive and guided progression through the course content. Additional attention will be given to grouping related materials and improving the overall coherence of the unit-level learning experience. These refinements are reflected in the revised syllabus through the revised pedagogical structure and improved organisation of learning elements.

A third refinement line has to do with the **adaptation of assessment design to support incremental learning**. Based on feedback regarding quiz design and usability, self-evaluation quizzes will be revised to become shorter, more targeted, and better aligned with the updated content structure. Where necessary, quizzes will be divided into smaller assessment units to support step-by-step knowledge verification and reduce cognitive load. The aim is to maintain the formative role of quizzes while improving their clarity, usability, and effectiveness as learning support tools. These refinements are reflected in the revised syllabus through the updated assessment approach and redesigned self-evaluation activities.

The fourth refinement suggests **strengthening of applied learning elements and content balance**. In order to enhance the practical dimension of the course, additional exercises and applied tasks will be introduced, enabling learners to better connect theoretical concepts with real-world use cases. At the same time, selected content will be streamlined to reduce repetition and optimise information density. Where appropriate, supplementary materials will be repositioned as optional resources, allowing learners to engage with additional content without overloading the core learning flow. These refinements are reflected in the revised syllabus through the inclusion of applied tasks and the improved balance of core and supplementary materials.

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These targeted refinements ensure a clear alignment between learner feedback, pedagogical improvements, and their practical implementation, while strengthening the coherence between pilot outcomes and the final course design presented in the syllabus (Annex I).

Scope	Refinement area	Adjustment
Video lectures	Video delivery and engagement	Restructure video lectures into shorter, focused segments to improve engagement and learning pace; reduce reliance on AI-generated narration and introduce human voice where feasible
Learning units structure	Internal structure and navigation	Introduce a consistent sequence of learning elements (video → material → quiz → exercise) and improve grouping of content to support clearer navigation and learning flow
Assessment	Assessment design	Adapt self-evaluation quizzes into shorter, targeted units aligned with content; support step-by-step knowledge verification and reduce cognitive load
Practical activities	Practical engagement	Introduce additional applied tasks and exercises to strengthen the link between theoretical concepts and real-world use cases
Learning materials	Content balance	Streamline content to reduce redundancy and reposition selected materials as optional to avoid overloading the core learning pathway

Table 2. Summary of refinement actions

3.2. Network Architecture and Protocols

3.2.1. Course Implementation

The course **Network Architecture and Protocols** was implemented in the Moodle learning environment as part of the 5G-DiGITs curriculum to provide learners with a comprehensive and academically rigorous understanding of the architectural foundations, operational mechanisms, and protocol structures underpinning 5G and emerging Beyond-5G communication systems. Designed for a workload of **60 hours** corresponding to **2 ECTS**, the course targets learners in engineering and ICT-related disciplines and combines theoretical instruction with analytical exercises and case-based learning to strengthen both conceptual and applied competencies.

In line with the curriculum framework established in Deliverable D2.2, the course is organised into **four modules**, progressing from introductory material on 5G system evolution to the advanced study of RAN and Core Network protocols, virtualised architectures, QoS mechanisms, and early 6G research perspectives. The course design ensures pedagogical continuity across modules while supporting independent progression through structured digital learning resources.

<u>Module 1 – Introduction to 5G Networks</u>

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Module 1 establishes the conceptual foundations of the course by introducing learners to the evolution of mobile communication systems and the architectural principles defining contemporary 5G networks. It includes **three units** covering historical progression, network components, and early application domains.

Unit 1.1 – Evolution of Mobile Networks

This unit, divided into **three sections**, guides learners through the development of cellular systems from the first generation of analogue telephony to the emergence of 5G. The lesson sections begin by presenting the operational logic of cellular architectures and the key concepts governing mobile system design, then move into a historical examination of 1G through 4G developments. The unit concludes with an introductory discussion of 5G standards and their early specification milestones, bridging the historical evolution with modern technological drivers.

Unit 1.2 – Key Components of the 5G Architecure

Unit 1.2, divided into **three sections**, introduces the main architectural elements of 5G systems. Learners explore the structure and function of the **3GPP 5G Radio Access Network (RAN)**, followed by a detailed overview of the **3GPP 5G Core Network (5G CN)** and its cloud-native properties. The unit also incorporates a comparative analysis of 4G EPC and 5G Core, enabling students to understand the transition toward a service-based, virtualised architecture.

Unit 1.3 – 5G Use Cases and Applications

The final unit (**one section**) of Module 1 contextualises 5G within its core service categories: **enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communications (URLLC), and massive Machine-Type Communications (mMTC)**. Through examples and domain-specific illustrations, learners examine how 5G adapts to diverse performance requirements across industrial and societal sectors.

Module 2 – 5G Radio Interface and RAN

Module 2 deepens the technical analysis of 5G by addressing spectrum usage, physical-layer technologies, and RAN deployment models. Spanning **three units**, the module provides a detailed exploration of spectral resources, 5G NR design principles, and RAN protocol stacks.

Unit 2.1 – 5G Spectrum and Frequency Bands

This unit, divided into **six sections**. introduces the structure of 5G spectrum allocation, beginning with a general overview of frequency bands and moving into detailed discussions of **FR1 sub-6 GHz bands, FR2 mmWave bands**, and use-case-specific allocations. Subsequent sections address **Dynamic Spectrum Sharing (DSS)** and the operational challenges associated with high-frequency deployments. The unit concludes with future-trend considerations in spectrum management.

Unit 2.2 – 5G New Radio

Unit 2.2 (**six sections**) examines the fundamental design of 5G NR, presenting its waveform, modulation and coding options, numerology, frame structure, and physical channels. Dedicated sections introduce key technologies such as **MIMO beamforming**, as well as **Dual Connectivity** and **Carrier Aggregation**, enabling learners to understand how NR achieves flexibility, scalability, and high spectral efficiency.

Unit 2.3 – 5G RAN Deployment Modes and Protocols

The third unit, divided into **four sections**, provides a comprehensive view of RAN deployment strategies, contrasting **Non-Standalone (NSA) and Standalone (SA)** architectures and explaining

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their implications for performance and interoperability. It also introduces the 5G **RAN protocol stack**, from PHY and MAC up to RRC and signalling layers. The unit concludes with a comparative analysis of RAN design choices, including aspects relevant to future network evolution.

Module 3 – 5G Core Network and Network Slicing

Module 3 turns to the service-based, virtualised core of 5G systems and the enabling technologies behind network slicing and low-latency service delivery. It is organised into **three units**.

Unit 3.1 – 5G Core Network and the SBA Model

This unit is divided into **three sections**. It introduces the **Service-Based Architecture (SBA)** and explains how 5G CN design departs from traditional EPC approaches. Learners examine the principles of service-based interactions, the decomposition of network functions into service roles, and the protocol exchanges that underpin registration, session management, and policy control. Practical scenarios illustrate how SBA facilitates flexibility and dynamic service provisioning.

Unit 3.2 – SDN/NFV and MEC in 5G

Spanning across **three sections**, Unit 3.2 focuses on the virtualisation and orchestration frameworks enabling modern 5G deployments. Dedicated lesson sections review the roles of **Software-Defined Networking (SDN), Network Function Virtualisation (NFV), and Multi-access Edge Computing (MEC)** in supporting programmable, agile network infrastructures. The unit also highlights security considerations linked to virtualisation and edge deployment, complementing architectural understanding with operational awareness.

Unit 3.3 – 5G QoS Architecture and Network Slicing

The final unit, divided into **two sections**, analyses **5G QoS mechanisms** and the architecture enabling end-to-end **network slicing**. Students learn how differentiated services can be delivered across shared physical infrastructures, how QoS flows are managed, and how slicing supports vertical-specific performance guarantees. A concluding analytical component explores the implications of slicing for deployment strategies and service delivery.

Module 4 – B5G/6G Concepts and Future Trends

Module 4 looks beyond contemporary 5G systems toward emerging 6G technologies and the integration of AI within future networks. It comprises **two units**.

Unit 4.1 – Beyond 5G Evolutions – Towards 6G

This unit (**four sections**) introduces the early vision, motivation, and research directions guiding the transition from 5G to 6G. Learners explore new spectral frontiers such as **THz and optical bands**, the **integration of sensing and communication**, and the emerging role of **non-terrestrial networks** in global connectivity.

Unit 4.2 – AI and Machine Learning in B5G/6G Systems

The second unit includes **eight sections** and offers a comprehensive overview of **AI/ML use in future communication systems**. Topics include ML-based optimisation of PHY-layer functions, resource management, integrated sensing communication, network automation, and approaches such as federated learning and explainable AI. Through this unit, learners understand the trajectory toward AI-native 6G architectures.

Additional Learning Components Implemented in the Moodle Course

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In addition to the core modules and units, two supplementary components are included to enrich the applied and industry-oriented dimensions of the course:

Industrial Guest Lecture

A dedicated lecture titled "**5G Testing Challenges in Public and Private Networks**", delivered by **Rohde & Schwarz Mobile Network Testing**, provides learners with insights into industry-level challenges in testing methodologies, performance evaluation, and deployment realities of 5G networks.

Problem-Based Learning (PBL) Case Study

The course concludes with a PBL final project titled "**Identifying Key Performance Indicators (KPIs) and Key Value Indicators (KVIs) for Beyond-5G Use Cases: Remote and Immersive eHealth Education**". This activity guides students through the analysis of service requirements, performance metrics, and value dimensions for advanced B5G applications, supporting the transfer of theoretical and architectural knowledge to realistic future-network scenarios.

Pedagogical Structure and Learning Resources

Across all modules, the course follows a consistent pedagogical structure within the Moodle LMS. Each lesson includes a recorded video lecture accompanied by presentation slides with speaker notes, functioning as transcript-style support material. Learners can choose between video-based and reading-based study formats, enhancing accessibility and flexibility.

To consolidate learning, formative self-evaluation quizzes follow each unit, enabling students to verify comprehension before progressing. Selected units incorporate practical exercises or short written reflections, supporting the development of applied problem-solving skills. Additional reading materials and curated references provide opportunities for deepening conceptual and technical understanding.

The digital learning environment ensures a structured, self-paced progression through modules, with consistent navigation, clear learning objectives, and balanced use of textual, visual, and interactive learning resources.

3.2.2. Feedback and Observations

This report is based on a total of 39 responses collected through a course evaluation survey. The participant profile is composed primarily of Master's students, followed by PhD and Bachelor students.

From a quantitative perspective, the overall evaluation of the course is strong and clearly positive. Most responses fall within the 4 to 5 range, particularly in relation to aspects such as structure and organization, clarity and consistency, quality of materials, theoretical foundation, and the value of the case study component. Although the general trend is highly favorable, a moderate level of dispersion is observed. This variability is mainly associated with issues related to AI-narrated videos, concerns about quiz design—including excessive length, repetition, and occasional technical errors—and a perceived workload that many students consider too demanding for a 2-ECTS course.

The highest-rated aspects of the course include its clear and coherent structure, which students find easy to follow, as well as the clarity of content and consistency in terminology. The course is also valued for its relevance to current technological developments and for providing a solid theoretical foundation, particularly in areas such as 5G architecture, SDN, NFV, and MEC. Additionally, the case study component, despite being considered demanding, is widely recognized as a valuable learning element.

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Conversely, lower ratings are associated with reduced engagement in sections where AI-generated voiceovers are used, as well as with the limited degree of practical application. Students frequently express the need for more hands-on and interactive activities. Assessment methods also receive criticism, particularly due to the perceived overload of quizzes, repetition of questions, and the presence of system-related issues. Navigation is another area of concern, as some students find the organization of quizzes and materials within units overly dense and difficult to navigate.

From a qualitative standpoint, several key strengths emerge. First, the course is consistently recognized for the high quality and relevance of its content. Students highlight that it covers the main components of modern 5G architecture, incorporates cutting-edge topics such as SDN, NFV, MEC, network slicing, and RAN evolution, and includes industry-aligned materials, notably through guest lectures. Second, the course demonstrates strong structural coherence, with modules organized in a logical and sequential manner. The slides are described as clear and not overloaded, and videos presented by human instructors in several units significantly enhance engagement. Third, the perceived value of the course is notably high, with many students explicitly describing it as one of the best-structured courses in the program and praising the quality of the guest lectures. Finally, there is a strong alignment between modules, assessments, learning outcomes, and case studies, contributing to a coherent overall learning experience.

Despite these strengths, several weaknesses are consistently identified. One of the most prominent issues concerns the excessive length and suboptimal design of quizzes. Many students report quizzes containing between 50 and 80 questions, with repeated items both within and across quizzes. Additional problems include incorrectly implemented multiple-answer questions presented as single-choice, and a system design where a single incorrect answer may require restarting the entire quiz. This represents one of the most significant negative patterns in the dataset.

Another major concern is the workload, which many students perceive as disproportionate to the assigned 2 ECTS credits. Several respondents describe it as comparable to that of a 5-credit course, highlighting in particular the time required for the practical components and the case study. Issues related to AI-generated voiceovers are also frequently mentioned, including a monotonous and mechanical tone, difficulty maintaining attention, audio glitches such as echo or duplication at specific points, and pronunciation problems, especially with technical terminology.

Some students also report occasional overlaps in content, with certain topics—such as RAN—being explained repeatedly across different modules. In addition, navigation is sometimes perceived as cumbersome due to the large number of materials presented simultaneously. A number of respondents suggest that the course will benefit from a clearer roadmap on the main page and from improved grouping of videos, quizzes, and downloadable resources.

Participants provide several constructive suggestions for improvement. A primary recommendation is to redesign the quiz system by reducing the number of questions to a more manageable range (approximately 15 to 25), eliminating repetition, dividing longer quizzes into smaller sections, correcting multi-answer functionality, and allowing partial completion without requiring a full restart. Students also emphasize the need to enhance practical engagement through the inclusion of interactive activities in each module, more guided exercises, richer case-based scenarios, and clearer estimates of the time required for practice tasks.

In terms of video delivery, respondents suggest replacing AI-generated narration with human-recorded audio, eliminating technical audio issues, ensuring consistent use of subtitles, and maintaining the instructor's presence on screen, even if only in a small window. Additional recommendations include the introduction of a course roadmap with concise summaries of each module, guidance on the recommended learning sequence, and improved navigation through

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better organization of materials. Some students also propose expanding the content to include specific topics such as cybersecurity in 5G and providing more real-world deployment examples.

In conclusion, the course on Network Architecture and Protocols emerges as one of the strongest offerings within the program. Its main strengths lie in the high relevance of its content, excellent structural coherence, clarity of presentation, well-designed instructional materials, valuable guest lectures, and a consistent and robust theoretical foundation. The primary weaknesses identified are procedural rather than academic in nature, including overly long and sometimes flawed quizzes, reduced engagement due to AI-generated narration, a workload that appears disproportionate to the assigned credits, and the need for greater interactivity and improved navigation.

3.2.3. Refinements and Adjustments

Based on the pilot implementation and the feedback collected from participating learners, the refinement strategy for the Network Architecture and Protocols course primarily targets issues related to delivery quality, assessment design, workload balance, and learner engagement, while preserving the course's strong academic foundation and coherent structure. The pilot results clearly indicate that the course content is highly relevant, well aligned with learning objectives, and academically sound; therefore, the proposed refinements focus on procedural and pedagogical improvements rather than substantive changes to the curriculum scope.

A first area of refinement concerns the **assessment strategy**, particularly the design and implementation of quizzes. Learner feedback consistently highlighted excessive quiz length, repetition of questions, and technical issues related to multi-answer items and forced quiz restarts. In the refined version of the course, quizzes will be standardized across modules, with a reduced and more manageable number of questions per quiz, elimination of duplicated items, and correction of technical flaws. The aim is to preserve the formative role of quizzes while reducing frustration, cognitive overload, and misalignment with the 2 ECTS workload.

A second refinement line addresses **audiovisual delivery quality**, which emerged as one of the most significant factors affecting learner engagement. The use of AI-generated voiceovers in some of the lectures was repeatedly identified as monotonous and detrimental to sustained attention, particularly in a technically dense course. The refined course version will therefore prioritize the optimization and/or replacement of AI-generated narration with human voice recordings wherever feasible, complemented by consistent subtitles and improved audio quality. This change is expected to enhance engagement, comprehension, and overall learning experience without altering the academic depth of the material.

Third, the refinement strategy places strong emphasis on strengthening **interactive and practice-oriented learning components**. While learners valued the theoretical rigor of the course, many expressed a desire for more hands-on and guided application of architectural and protocol concepts. To address this, in the refined course we plan to introduce additional interactive elements such as step-by-step protocol analysis and short practice tasks embedded within modules. These activities will be designed to reinforce conceptual understanding through applied reasoning, without significantly increasing overall workload.

A fourth refinement line concerns **navigation clarity and course-level orientation**. Feedback indicates that, although the internal module structure is coherent, learners will benefit from clearer guidance at the course entry level. The refined version will therefore include a concise course roadmap on the main page, outlining module objectives, recommended learning paths, and expected effort. Course materials will be reorganized into clearer and short module-level summaries will be added to support orientation and reduce cognitive load during navigation.

Workload alignment also constitutes an important refinement priority. Several learners perceived the overall effort required as high relative to the 2 ECTS allocation, particularly due to

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the cumulative effect of long quizzes and the PBL case study. In response, minor internal rebalancing will be undertaken by streamlining assessment density, eliminating content overlaps (especially across RAN-related units), and clarifying expected time commitments for practical tasks. These adjustments aim to improve proportionality without reducing the pedagogical ambition or analytical depth of the course.

Finally, the refinement strategy acknowledges learner interest in **expanding the technical portfolio through optional advanced topics**, particularly in the area of cybersecurity. While not introducing mandatory new workload, the refined course will integrate optional or complementary material addressing 5G security considerations, responding to recurring student requests and reinforcing the course's industry relevance.

Overall, as also summarized in the table below, the planned refinements for this course aim to transform an already strong technical course into a more engaging, usable, and workload-balanced learning experience. The focus remains on enhancing delivery quality, interactivity, and assessment proportionality, while fully preserving the course's academic rigor, structural coherence, and alignment with the objectives of the 5G-DiGITs curriculum.

Scope	Refinement area	Adjustment
Whole course	Assessment strategy	Standardise quizzes across modules, reduce excessive length, eliminate repeated questions, and resolve technical issues related to multi-answer logic. Clarify the distinction between formative self-evaluation and more substantial assessment activities.
Whole course	Audiovisual delivery	Replace or substantially reduce AI-generated narration with human voice recordings where feasible. Improve audio quality and pronunciation of technical terms, and ensure consistent use of subtitles to support accessibility and engagement.
Whole course	Practical engagement	Introduce additional guided applied activities, such as step-by-step protocol analysis, packet-flow visualisations, small simulations, and short practice-oriented tasks embedded within modules to strengthen theory–practice integration.
Whole course	Navigation and orientation	Add a concise course-level roadmap on the main page presenting module objectives, recommended progression, and expected effort. Improve grouping of materials (videos, quizzes, readings, assignments) and include short module-level summaries to support learner orientation.
Whole course	Workload balance	Rebalance assessment density and practical workload to better align with the 2 ECTS allocation. Simplify overly dense sequences and clarify time expectations for quizzes, exercises, and the PBL case study.
Modules 2-3	Content streamlining	Reduce minor overlaps and repetitions, particularly in RAN-related topics, by clarifying sequencing and sharpening conceptual focus across modules without reducing technical depth.

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PBL activities	PBL alignment	Maintain the strong analytical value of the PBL case study while refining guidance and expected outputs to ensure proportional effort and clearer alignment with learning outcomes.
Optional enrichment	Advanced topics	Introduce optional or complementary material on 5G security and related architectural considerations, responding to learner interest while avoiding additional mandatory workload.

Table 3. Summary of refinement actions

3.3. IoT, Industry 4.0, and Smart Cities

3.3.1. Course Implementation

The course **IoT, Industry 4.0, and Smart Cities** was developed within the 5G-DiGITs curriculum to enable learners to familiarize with IoT technologies within the 5G context and enable them to understand the role of 5G and IoT networks for the development of systems related to Industry 4.0 and Smart Cities. According to the curriculum design the course carries **2 ECTS** and a total workload of **60 hours**, and it is targeted for **undergraduate or postgraduate students** in the fields of **ICT and engineering**, as well as **early-career professionals** working in **city planning, smart infrastructure, or digital innovation** and p**ublic sector employees and policymakers** involved in **urban development and sustainability initiatives.**

The course is structured into three thematic modules:

- Module 1: IoT in 5G context
- Module 2: Industry 4.0 Technological and Vertical-specific challenges
- Module 3: Smart Cities in the 5G era

Module 1: IoT in 5G context

Module 1 provides an introduction to the foundational concepts of IoT and its interaction with modern communication technologies, with particular emphasis on the role of 5G in supporting large-scale, reliable, and energy-efficient connected systems. The main learning outcomes of the module are the familiarization with the evolution, core concepts, and key application domains of IoT, the understanding of the technological building blocks and communication solutions underpinning IoT systems, and the ability to analyze how cellular and 5G technologies support the integration of IoT into next-generation digital services and cyber-physical systems.

Module 1 is implemented in Moodle and organized in two units:

Unit 1.1 introduces learners to the origins, development, and practical relevance of IoT across multiple sectors. The unit begins with **an introduction to IoT**, which presents the historical evolution of IoT, from early microcontrollers and embedded systems to today's smart, sensor-driven, and interconnected devices, while also explaining the technological advances that made IoT possible. This is followed by an analysis of **IoT in Industry 4.0/energy**, where learners examine how IoT supports smart factories, predictive maintenance, automation, supply chain optimization, smart grids, renewable energy integration, and intelligent energy management. The unit then continues with a reference on **IoT in Healthcare and smart home**, focusing on the use of IoT in patient monitoring, remote diagnostics, hospital efficiency, connected appliances, smart lighting, climate control, and home security. Finally, a description of the area of **Retail and agriculture** explores how IoT technologies contribute to smart retail environments, inventory tracking, automated checkout, precision farming, smart irrigation, livestock monitoring, and environmental sensing. Overall, Unit 1.1 familiarizes learners with both the conceptual foundations of IoT and its wide-ranging impact across industrial and societal domains.

Unit 1.2 shifts the focus to the technical foundations of IoT systems and the communication technologies that support their operation, with particular attention to the role of 5G. The unit starts with a section on **Microcontroller, Sensor, and System software**, which introduces the fundamental hardware and software components of IoT edge devices, including microcontrollers, sensors, firmware, and lightweight operating systems. It then proceeds to **IoT Networking Basic**, where learners are introduced to the essential principles of data communication, networking structures, and protocol-based information exchange. Building on this, **IoT Networking Protocol** examines the main protocols and technologies used in IoT systems, including Wi-Fi, Bluetooth, Zigbee, LoRaWAN, 6LoWPAN, LTE-M, and NB-IoT, while highlighting their relevance for low-power and large-scale deployments. The next section, **Cellular IoT**, focuses on the integration of IoT with mobile communication systems and explains how cellular infrastructures support wide-area IoT deployments with strong coverage, security, and scalability. This is followed by **Narrowband IoT (NB-IoT)**, which presents NB-IoT as a dedicated low-power wide-area technology and explains its architecture, operational principles, and energy-saving mechanisms. The discussion is then extended in **IoT in 5G**, where the native support of IoT within the 5G ecosystem is addressed through concepts such as massive connectivity, high reliability, low latency, network slicing, and edge computing. Finally, **IoT Application Protocol** introduces application-layer protocols such as MQTT, CoAP, and ZeroMQ, enabling learners to understand how IoT devices exchange, structure, and interpret data once connectivity has been established. Taken together, Unit 1.2 provides learners with the technical understanding required to analyze how IoT devices communicate and how 5G enhances their deployment and operation.

Each lesson in **Module 1** follows a consistent pedagogical structure. The units are divided into sections, and for each section learners are provided with a video lecture, the corresponding presentation slides, and speaker notes that serve as transcript-style support material. At the end of each unit, a self-evaluation quiz is included to allow learners to assess their understanding of the main concepts covered. In addition, curated references to further reading materials are provided to support self-study and promote deeper engagement with the subject matter. This structure was designed to facilitate asynchronous, self-paced learning while maintaining consistency across all sections of the module.

The workload of **Module 1** was monitored using the methodology applied to the implemented units, distinguishing between lecture hours, exercise hours, and self-study hours. The total workload was estimated at **5 hours for Unit 1.1** and **15 hours for Unit 1.2**. For both units, the workload distribution follows the same structure: **35% lecture**, **25% exercises**, and **40% self-study**. For **Unit 1.1**, this corresponds to **1.75 hours of lecture**, **1.25 hours of exercises**, and **2 hours of self-study**. For **Unit 1.2**, the workload corresponds to **5.25 hours of lecture**, **3.75 hours of exercises**, and **6 hours of self-study**.

In pedagogical terms, **Module 1** combines introductory theoretical background, representative use cases, and core technical knowledge in embedded systems, networking, and communication technologies. The first unit is designed to build a broad understanding of IoT as a concept and as an enabler across different application sectors, while the second unit develops the technical foundation required to understand how IoT systems sense, process, communicate, and integrate into advanced 5G-enabled network environments. Overall, the aim of the module is to establish a strong and coherent basis for further study, enabling learners to understand both the practical significance of IoT and the communication technologies that underpin its real-world deployment.

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Module 2: Industry 4.0 Technological and Vertical-specific challenges

Within the overall framework of the course, Module 2 is focused on exploring the application of advanced wireless networks and IoT technologies within the industrial (manufacturing) landscape, along with the requirements, implications and challenges for adoption of these technologies. The main learning outcomes of the module are the familiarization with IoT technologies and related use cases in Industry 4.0, the understanding of the key research challenges and implications for the convergence of OT and ICT systems and the design and analysis of data management and data-driven optimization systems for manufacturing.

The module is implemented in Moodle and organized in two units:

- Unit 2.1: Industry 4.0 potential for Manufacturing
- Unit 2.2: IoT technologies used in Industrial environments

Unit 2.1 examines the role of IoT in the context of Industry 4.0, enabling learners to understand the core principles and key enabling technologies of Industry 4.0 and Industrial IoT, as well as the challenges and implications of their implementation. The lesson-level sections start with an introduction of the foundations of Industry 4.0 in manufacturing to familiarize learners of fields not directly linked with the manufacturing sector. The next sections dive deeper into the enabling technologies of Industry 4.0, such as smart factory, cyber-physical production systems, data-driven manufacturing and integration of AI, as well as the application of robotics in manufacturing. Finally, the unit concludes with a section on implementation strategies and real-world applications of these technologies. The last unit also includes a hands-on exercise, where learners can apply the knowledge gained throughout the unit.

Unit 2.2 shifts the focus to the communication technologies that enable the networking between the IT and OT systems described in Unit 2.1. The sections of the unit start with an introduction of the core components of industrial IoT and its ecosystem. Then, the components comprising an IoT architecture (sensors, actuators, communication technologies) are analyzed, with a special focus on the latter. The requirements and strategies to match hardware and network technologies to achieve OT and ICT systems convergence are highlighted. Next, computing strategies (edge, fog, cloud) are presented and discussed, along with deployment strategies for industrial IoT systems and a detailed walkthrough of the implementation of a 5G-enabled monitoring system for manufacturing processes. The concludes with the presentation of the Green dimension of IoT, focusing on decision trade-offs between performance and sustainability.

Each lesson in Module 2 follows a consistent pedagogical format. Units are broken down into sections, for which learners are provided with **a video presentation and the corresponding presentation slides and speaker notes used as transcript-style support material.** In the end of each unit, **a self-evaluation quiz** is included, so that learners can evaluate their understanding regarding the key concepts of each unit. Finally, a **curated selection of reading material (academic papers, technical papers, industry reports)** has been included as **a self-study mechanism.** This format was designed to support asynchronous, self-paced learning while ensuring consistency across the module sections.

The workload of Module 2 was monitored using the methodology applied to the implemented units, distinguishing between **lecture hours, exercise hours, and self-study hours.** For **both Units**, the initially planned workload was 10 hours each. **For Unit 2.1**, the total workload reached approximately **10 hours 11 minutes**, which is broken down into **3 hours 41 minutes of lecture time, 2 hours 30 minutes of exercise and 4 hours of self study. For Unit 2.2**, the total workload reached approximately **10 hours 1 minute**, which is broken down into **3 hours 31 minutes of lecture time, 2 hours 30 minutes of exercise and 4 hours of self study**

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In pedagogical terms, Module 2 combines **theoretical background in the technologies themselves, as well as the peculiarities of the industrial sector that are applied to, formative self-assessment, and practice-oriented case-study work.** The hands-on activities and guided walkthroughs were intended to support practical application, provide a real-world experience of similar problems to learners and intrigue their self-directed investigation and critical thinking. Overall, the aim of the module is the best possible transfer of the acquired knowledge to real-world applications of Industrial Internet of Things.

Module 3: Smart Cities

Within the overall framework of the course, Module 3 focuses on exploring the concept of Smart Cities and the role of IoT technologies, data platforms, and digital infrastructure in enabling sustainable and intelligent urban environments. The module examines how integrated digital technologies, stakeholder collaboration, and data-driven decision-making support the transformation of cities into more efficient, resilient, and citizen-centric ecosystems. The main learning outcomes of the module are the familiarization with the core concepts and technological components of smart cities, the understanding of the stakeholder ecosystems and governance models involved, and the ability to analyze data platforms, interoperability mechanisms, and sustainability strategies that underpin modern urban innovation.

The module is implemented in Moodle and organized in two units:

- Unit 3.1: Introduction to IoT Smart Cities
- Unit 3.2: Smart Cities Concept

Unit 3.1: “Introduction to Smart Cities” introduces the concept of smart cities and examines how digital technologies such as IoT, sensors, and data analytics transform urban environments and address key urban challenges. The sections of this unit present the fundamental principles of smart cities, focusing on the integration of data, technology, and human-centered design to improve urban living. Learners are introduced to the major domains of smart cities, including mobility, public safety, energy management, environmental monitoring, governance, and digital inclusion. The unit also highlights the role of IoT devices and data-driven systems in enabling real-time monitoring and decision-making across urban services. Through practical use cases, such as smart transportation systems and environmental monitoring solutions, learners gain an understanding of how technology supports more efficient and responsive urban operations.

Unit 3.2 “Smart Cities Concept” focuses on the technological infrastructure that enables smart city ecosystems. The unit begins with the concept of smart infrastructure, emphasizing how traditional urban systems such as transportation, energy grids, and water networks are enhanced through the integration of IoT sensors, connectivity technologies, artificial intelligence, and cloud computing platforms. These technologies transform static infrastructure into dynamic and responsive systems capable of real-time monitoring, predictive maintenance, and resource optimization. The unit also explores urban data platforms, which act as centralized digital environments that collect, manage, and share urban data among multiple stakeholders. Particular emphasis is placed on interoperability, data exchange standards, and semantic frameworks that enable different urban systems to communicate effectively. The unit also addresses governance aspects such as data ownership, privacy, transparency, and ethical considerations associated with large-scale urban data management.

The unit also analyzes how digital technologies such as IoT sensors, artificial intelligence, and data analytics support sustainable practices in areas such as energy management, environmental monitoring, waste management, and sustainable mobility. By leveraging real-time data and predictive analytics, cities can optimize resource usage, reduce emissions, and

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improve resilience to climate challenges. The unit concludes by emphasizing the role of innovation ecosystems and citizen participation in ensuring that technological advancements translate into meaningful improvements in urban quality of life.

Pedagogical Approach

Each lesson in Module 3 follows a consistent pedagogical structure similar to the previous modules. The units are divided into thematic sections, each accompanied by a video presentation, presentation slides, and speaker notes that function as transcript-style support material. At the end of each unit, learners complete a series of self-evaluation quizzes designed to assess their understanding of the key concepts presented throughout the unit. In addition, curated reading materials, including academic papers, technical reports, and industry publications, are provided to support further independent study.

The overall pedagogical design aims to support asynchronous and self-paced learning, while maintaining consistency in content structure and instructional delivery across all units.

Workload

The workload of Module 3 was monitored using the same methodology applied to the previous modules, distinguishing between lecture hours, exercise hours, and self-study hours. Each unit was designed to correspond to an estimated total workload of approximately 10 hours, distributed across video lectures, practical exercises, and individual study activities.

Educational Objectives

From a pedagogical perspective, Module 3 integrates theoretical foundations with practical urban innovation scenarios. The module combines conceptual knowledge of smart city technologies with applied perspectives on governance, data platforms, infrastructure systems, and sustainability strategies. Through examples, analytical frameworks, and real-world use cases, learners are encouraged to critically examine how digital technologies and collaborative ecosystems contribute to the transformation of cities into more efficient, resilient, and sustainable environments. Overall, the aim of the module is to facilitate the effective transfer of knowledge related to IoT-enabled smart cities and data-driven urban innovation, enabling learners to understand and apply these concepts in real-world urban development contexts.

3.3.2. Feedback and Observations

This report is based on a total of 33 responses collected through a course evaluation survey.

In general terms, the course is well rated, with a significant proportion of scores falling within the 4 to 5 range. However, the results also show a moderate level of dispersion, indicating some variability in student perceptions.

From a quantitative perspective, the course receives high scores in areas such as content relevance, clarity, and overall structure. Greater variation is observed in aspects related to the balance between theory and practice, as well as in overall satisfaction levels. Differences across student profiles are also evident: Bachelor’s and Master’s students tend to report higher levels of satisfaction, while PhD students adopt a more critical perspective.

Among the most highly valued aspects, students highlight the relevance of the content, the logical progression of the material, and the strength of the first module, particularly due to the use of human narration. The alignment with real-world applications is also positively perceived, along with the availability of downloadable supporting materials.

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Despite these strengths, several weaknesses are consistently identified. Students report structural inconsistencies between modules, an excessive reliance on AI-generated narration, and limited opportunities for practical application. Additional concerns include content repetition and a lack of homogeneity across the course.

The qualitative analysis reinforces these findings. On the positive side, the course is recognized for providing solid introductory coverage, featuring a particularly strong first module, maintaining a logical progression, and offering useful supporting materials. On the negative side, students point to an uneven structure, reduced engagement due to AI-generated voiceovers, insufficient practical application, repetition of content, and a certain degree of fragmentation arising from the involvement of multiple instructors.

Participants also propose several areas for improvement. Key recommendations include standardizing the structure across all modules, reducing the use of AI narration, incorporating more practical and interactive activities, minimizing content repetition, and improving overall coherence.

In conclusion, the course is perceived as highly valuable in terms of content and learning potential, but it is affected by structural inconsistencies that limit the overall effectiveness of the learning experience.

3.3.3. Refinements and Adjustments

The pilot feedback collected for the course *IoT, Industry 4.0, and Smart Cities* indicates an overall positive evaluation, while also highlighting several recurring issues related to structural consistency, learner engagement, and the balance between theoretical content and practical application. A total of 33 responses were analyzed, showing generally high scores in relevance, clarity, and logical progression, with most evaluations falling between 4 and 5. These results confirm that the course is perceived as valuable, well-aligned with current technological developments, and effective in introducing key concepts related to IoT systems, Industry 4.0 applications, and smart city ecosystems.

The strongest aspects identified in the feedback include the relevance of the content, the logical progression of topics, and the quality of the introductory module, particularly where human narration was used. Learners also appreciated the availability of downloadable materials and the alignment of the course with real-world applications. These elements demonstrate that the course successfully establishes a solid conceptual foundation and provides meaningful insights into the role of IoT and 5G technologies in modern industrial and urban environments.

At the same time, the feedback highlights several areas where further improvement could be beneficial.

The first area for refinement is related to the **course structure**. This does not concern the structure at module-level, which is perceived as generally good, but mainly the structural differences between each individual module, as well as the structure of the course as a whole. This issue is important as it may influence the overall consistency of the learning experience. This may partly reflect variations in instructional approaches and the involvement of multiple instructors, resulting in some differences in how the courses are presented. Concerning this issue, it is proposed to introduce a standardized module template (organizing the introduction, content, examples, activities and quizzes) and rearrange the existing content upon this template.

The second area for refinement, tightly related to the first one, is related to the **coherence of the course and repetition of the same concepts and content across modules.** The repetition appears to stem from the involvement of multiple contributors and from an effort to reinforce

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key concepts throughout the course. Along with the restructuring and standardization of the different modules, an extensive review is required to streamline the content across all three. Issues, such as repetition of the same information will be resolved and any required elements will be added to enhance the perceived continuity between the modules, therefore tightening the coherence of the overall course.

The next area for refinement is related to the **delivery of the course, and specifically, the excessive use of AI-generated narration**. According to the available feedback, the excessive use of AI-generated narration in several parts of the course is reported to reduce engagement, as learners find it less effective for maintaining attention compared to human-delivered content. In the same area, another comment of the course participants highlighted the fragmentation between instructors, which is a result of the fact that the course is developed by multiple partners with different expertise and approaches To address this issue, replacement of AI-generated narration with human narration is proposed, to the extent that it is feasible, preferably by the same instructor across all modules, to ensure consistency in the course delivery.

The next refinement area that has been identified is the **integration of practical earning components and activities**. While the theoretical coverage is generally well received, learners express the need for more hands-on exercises, guided tasks, and real-world scenarios to better support the application of concepts. To address this issue, integration of additional hands-on exercises guided activities, and real-world case studies is proposed, consistently among the different modules. Moreover, the inclusion of simple comparison tables, quick “Did you know?” insights, connecting theoretical concepts to real-industrial examples and connection of the theoretical content to more practical examples, available in the downloadable material, will also strengthen the practical relevance of each unit and increase engagement.

Another interesting insight that drives a potential area for refinement is the **variation in learner satisfaction and critique regarding the theory-practice imbalance between different student profiles** (with PhD students standing more critical compared to Bachelors/Masters). This is something to be expected, considering the academic background, knowledge, and expertise among the different student profiles. To address this, it is proposed to add optional supplementary materials (basic vs. advanced) to suit different learner profiles and better clarify the learning objectives at the start of each module, to ensure that the expectations that are set will match what will be delivered in the end.

Overall, the feedback suggests that the course is academically sound and highly relevant, but improvements are needed in order to provide the best possibles outcome. The following list provides a list of updates and potential solutions.

Scope	Refinement area	Adjustment
Whole course	Course structure	Introduce a standardized module template (intro, content, examples, activity, quiz, summary) and align structure across all units
Module 3	Course structure	• Rename sections for clarity and consistency (use clear, descriptive titles). • Add short text introductions before each lesson (2–3 lines explaining purpose). • Provide a glossary of key terms for quick reference.

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		• Add an introduction/motivation at the beginning
Whole course	Course coherence	• Streamline content across all modules • Identify repeated content and eliminate it • Add elements to improve continuity and coherence between modules
Module 2 and 3	Course delivery	Replace AI-generated narration to the extent that is possible, preferably using a single instructor among all modules
Whole course	Practical components	• Integrate hands-on exercises, guided activities, and real-world case studies • Include simple comparison tables • Integrate quick "Did you know?" insights linking concepts to industry use. • Provide connection with the "Case studies, success stories and lessons learned - Event resource - Material/resources for downloading & External links sections of the Moodle"
Whole course	Variation in learner satisfaction	• Add optional supplementary materials (basic vs. advanced) to suit different learner profiles. • Clarify learning objectives at the start of each module.

Table 4. Summary of refinement actions

3.4. Energy Efficiency and Sustainability in Advanced 5G Technologies

3.4.1. Course Implementation and Pilot Context

The course **Energy Efficiency and Sustainability in Advanced 5G Technologies** was developed within the 5G-DiGITs curriculum to address the technical, environmental, regulatory, and business dimensions of sustainability in advanced 5G systems. According to the curriculum design, the course carries **2 ECTS** and a total workload of **60 hours**, and is primarily intended for learners in **ICT, engineering, and related technological fields**, including students at **Bachelor's, Master's, and PhD level**, as well as other learners interested in sustainable 5G deployment. The course is structured into four thematic modules:

- Module 1: Fundamentals of Energy Consumption in 5G Networks
- Module 2: Energy Efficiency Techniques and Network Optimization
- Module 3: Renewable and Hybrid Energy Integration in 5G
- Module 4: Regulatory, Policy, and Market Perspectives

<u>**Module 1 (Fundamentals of Energy Consumption in 5G Networks)**</u>

Within the overall course framework, Module 1 introduces the fundamental concepts of energy consumption in 5G systems. It contributes to learning outcomes related to understanding how

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energy is consumed across network components, interpreting energy usage patterns, and recognising the environmental implications of telecom infrastructure throughout its lifecycle.

In the Moodle implementation, Module 1 was organised into two units:

- Unit 1.1: Introduction to Energy Flows in 5G
- Unit 1.2: Environmental Impact of Telecom Infrastructure

Unit 1.1 introduced the structural and operational aspects of energy consumption in 5G networks. It included lesson-level sections on key components of 5G architecture and their energy roles, energy distribution across radio access and core networks, identification of energy hotspots in mobile and fixed infrastructures, and comparative energy consumption across different generations of mobile technologies. The unit concluded with a structured learning sequence consisting of video-based explanations, transcript-style slides, references, guided data interpretation exercises, and a final knowledge consolidation activity integrated into the module-level assessment.

Unit 1.2 extended this foundation by focusing on the environmental and lifecycle implications of telecom energy consumption. Its sections addressed lifecycle assessment of 5G infrastructure, carbon emissions and energy sourcing in telecom operations, long-term sustainability challenges associated with network scaling, and the relationship between energy use and environmental degradation. The unit concluded with a case-oriented activity supported by video materials, transcript-style slides, guided readings, and a reflective task designed to feed into the final course deliverable.

Each lesson in Module 1 followed a consistent pedagogical format. Learners were provided with video presentations, presentation slides with transcript-style speaker notes, and self-evaluation quizzes aimed at reinforcing key concepts. In addition, guided reading tasks and reflective elements supported deeper conceptual understanding. This format ensured a structured and accessible learning experience aligned with asynchronous, self-paced study, while supporting clarity, coherence, and progressive knowledge development.

The workload of Module 1 was monitored using the same methodology applied across the course, distinguishing between lecture hours, exercise hours, and self-study hours. For Unit 1.1, the initially planned workload was 7 hours, while the implemented workload reached approximately 7 h 22 min, including lecture-based video content, guided exercises, and independent review. For Unit 1.2, the initially planned workload was 8 hours, and the implemented workload reached approximately 9 h 07 min, incorporating lecture materials, case-based readings, and reflective activities. These calculations accounted for lesson videos, transcript-supported slides, quizzes, and reading-based tasks. The monitoring indicated a moderate increase compared to initial estimates, suggesting the need for minor adjustments in content balance in future iterations.

From a pedagogical perspective, Module 1 combined foundational conceptual instruction, formative self-assessment, and introductory analytical tasks. The activities were designed to support understanding of core principles, interpretation of energy-related data, and initial engagement with sustainability challenges in telecom systems, forming a basis for the more applied and solution-oriented modules that follow.

Module 2 (Energy Efficiency Techniques and Network Optimization)

Within the overall course framework, Module 2 addresses the technical strategies and design approaches used to improve energy efficiency in 5G networks. It contributes to learning

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outcomes related to applying energy-saving techniques, analysing optimisation strategies, and evaluating sustainable network design solutions in real-world contexts.

Module 2 was implemented through two units:

- Unit 2.1: Strategies for Network Energy Efficiency
- Unit 2.2: Designing Sustainable Network Architectures

Unit 2.1 introduced core techniques for improving energy performance in 5G systems. It included lesson-level sections on energy-saving mechanisms such as sleep modes and dynamic resource allocation, energy-aware routing and load balancing, performance trade-offs in efficiency strategies, and the role of AI and automation in real-time network optimisation. The unit concluded with a structured sequence of video-based lessons, transcript-style slides, simulation-oriented demonstrations, and applied tasks that contributed to the overall course assignment.

Unit 2.2 built on this technical foundation by focusing on the design of sustainable 5G network architectures. Its sections addressed principles of energy-aware network planning, sustainable design of radio access networks, fronthaul and backhaul optimisation, infrastructure upgrade decisions based on environmental criteria, and emerging architectural models prioritising energy efficiency. The unit concluded with a design-oriented activity supported by example-based tutorials, annotated diagrams, transcript-style slides, and a practical block integrated into the final deliverable preparation.

As in other modules, the lessons in Module 2 followed a standardised digital format consisting of video presentations, slides with transcript-style support, and self-evaluation quizzes. This consistent structure enabled learners to progress independently while maintaining alignment between theoretical content, applied examples, and assessment components. It also supported engagement, clarity, and the effective integration of technical and practical knowledge.

The workload of Module 2 was monitored using the same calculation approach. For Unit 2.1, the initially planned workload was 9 hours, while the implemented workload reached approximately 10 hours, including lecture content, simulation walkthroughs, and applied exercises. For Unit 2.2, the initially planned workload was 6 hours, with an implemented workload of approximately 7 h 18 min, incorporating design activities, guided analysis, and supporting materials. These estimates were based on the duration of lesson videos, simulation activities, quizzes, and independent study components. The monitoring showed that both units exceeded initial expectations, particularly Unit 2.1, indicating the need for potential workload redistribution in future course refinement.

From a pedagogical perspective, Module 2 combined technical instruction, applied optimisation tasks, and formative assessment. The inclusion of simulations, design exercises, and scenario-based activities supported the development of practical skills, problem-solving abilities, and the application of energy efficiency concepts in realistic 5G network contexts. This approach strengthened the connection between theoretical knowledge and real-world implementation, preparing learners for advanced topics in renewable integration and sustainability planning.

Module 3 (Renewable and Hybrid Energy Integration in 5G)

Within the overall course framework, **Module 3** addresses the integration of renewable and hybrid energy solutions into 5G systems. It contributes to learning outcomes related to understanding renewable energy systems for telecom applications, evaluating their technical and environmental relevance, and applying this knowledge to the design of greener deployment scenarios.

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In the Moodle implementation, **Module 3** was organised into two units:

- Unit 3.1: Renewable Energy Systems in Telecom
- Unit 3.2: Design of Green 5G Deployment Scenarios

Unit 3.1 introduced the role of renewable energy systems in supporting more sustainable telecom infrastructures. It included lesson-level sections on why sustainability and renewable energy matter in 5G, types of renewable energy for telecom, energy load profiles in telecom sites, sizing solar power systems for 5G sites, battery storage for telecom, and cost and financing of green 5G energy. The unit concluded with a case study supported by two video parts, transcript-style slides, references, a practical block, and a final deliverables upload area.

Unit 3.2 extended this perspective by focusing on the design of green deployment scenarios for 5G. Its sections addressed integrating renewables into 5G rollout planning, off-grid and rural deployment strategies, cost and carbon trade-offs in green deployments, site simulation using simulation tools, peer review in energy deployment scenarios, and policy and regulatory considerations. The unit concluded with a larger case-study-based activity implemented through three video-supported parts, transcript-style slides, a practical block, and a final deliverables submission area.

Each lesson in Module 3 followed a consistent pedagogical format. Learners were generally provided with a **video presentation**, the corresponding **presentation slides with speaker notes used as transcript-style support material**, and a **self-evaluation quiz** intended to reinforce the key concepts covered in the section. In addition, the unit-level case studies provided a more applied component through practical tasks and submission-based activities. This format was designed to support asynchronous, self-paced learning while ensuring consistency across the module's sections and strengthening aspects later addressed in the pilot evaluation, such as **course organisation**, **quality of learning materials**, **digital learning experience**, and **assessment usefulness**.

The workload of Module 3 was monitored using the methodology applied to the implemented units, distinguishing between **lecture hours**, **exercise hours**, and **self-study hours**. For **Unit 3.1**, the initially planned workload was **8 hours**, while the implemented workload reached approximately **9 h 19 min**. This final value comprised around **2 h 49 min of lecture time**, **3 h 00 min of exercise time**, and **3 h 30 min of self-study time**, including both the regular lesson materials and the case-study-related components. For **Unit 3.2**, the initially planned workload was **7 hours**, whereas the implemented workload reached approximately **12 h 03 min**, including around **4 h 45 min of lecture time**, **3 h 00 min of exercise time**, and **5 h 09 min of self-study time**. These calculations were based on the effective duration of lesson videos, case-study lecture materials, self-evaluation quizzes, practical exercises, transcript-supported slides, and references. The monitoring, therefore, showed that both units exceeded their initially planned workloads, particularly **Unit 3.2**, suggesting that some internal rebalancing may be considered in the refined version of the module.

In pedagogical terms, Module 3 combined **conceptual instruction**, **formative self-assessment**, and **practice-oriented case-study work**. The applied activities were intended to support practical application, authenticity of learning tasks, self-directed investigation, and the transfer of knowledge to realistic energy-deployment scenarios in telecom systems.

Module 4 (Regulatory, Policy, and Market Perspectives)

Within the overall course framework, **Module 4** addresses the regulatory, policy, and market dimensions of sustainability in advanced 5G systems. It contributes to learning outcomes related to understanding regulatory frameworks and compliance requirements, analysing energy and sustainability reporting mechanisms, and evaluating business and policy approaches that support greener telecom deployment.

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Module 4 was implemented through two units:

- Unit 4.1: Regulatory Frameworks and Compliance
- Unit 4.2: Business Models and Policy Innovation

Unit 4.1 introduced the regulatory and policy frameworks shaping how energy efficiency and sustainability are addressed in 5G and Beyond 5G networks. It included lesson-level sections on global sustainability agendas, the role of ITU, ETSI, 3GPP, and other bodies, regional and national adaptations, energy compliance frameworks, and lifecycle reporting and carbon metrics. The unit concluded with a case study supported by two video parts, transcript-style slides, supporting material, a practical block, and a final deliverables upload area.

Unit 4.2 focused on the economic and policy dimensions of sustainable 5G deployment. Its sections covered green investments in telecom, public-private financing models, ESG in the telecom context, and digital ethics and governance in relation to 5G sustainability. The unit concluded with a case study implemented through two video parts, transcript-style slides, a practical block, and a final deliverables submission area.

As in Module 3, the lessons in Module 4 followed a standardised digital format built around **video presentations**, **presentation slides with transcript-style speaker notes**, and **self-evaluation quizzes**. This format was intended to support independent progression through the content and to ensure a coherent structure across lessons and units. It also supported dimensions later captured in the pilot questionnaire, including **clarity and consistency**, **alignment between materials and learning objectives**, **engagement**, and the **usefulness of assessment and applied activities**.

The workload of Module 4 was likewise monitored using the same calculation methodology. For **Unit 4.1**, the initially planned workload was **8 hours**, while the implemented workload reached approximately **14 h 30 min**. This included around **5 h 20 min of lecture time**, **3 h 50 min of exercise time**, and **5 h 20 min of self-study time**. For **Unit 4.2**, the initially planned workload was **7 hours**, whereas the implemented workload reached approximately **9 h 26 min**, with around **2 h 40 min of lecture time**, **3 h 12 min of exercise time**, and **3 h 33 min of self-study time**. In both units, the calculations took into account lesson videos, self-evaluation quizzes, case-study lecture materials, practical exercises, transcript-supported slides, supporting materials, and recommended references. The monitoring, therefore, showed that **Unit 4.1** substantially exceeded the initial estimate, while **Unit 4.2** also exceeded the planned workload, indicating the need for further balancing within the refined course structure.

From a pedagogical perspective, Module 4 combined **regulatory and policy analysis**, **market-oriented sustainability content**, **formative self-assessment**, and **applied case-study work**. The practical tasks were intended to enable learners to connect compliance, reporting, policy, and innovation with sustainability-oriented decision-making in realistic telecom scenarios. This implementation logic is consistent with the broader curriculum approach, in which applied activities are used not only to reinforce understanding but also to encourage reflection, transfer, and contextualised problem-solving.

The Moodle course also included the **pilot evaluation survey**, through which learners were invited to provide structured feedback on course organisation, clarity, relevance, quality of resources, pedagogical approach, digital delivery, and, where applicable, the value of problem-based and case-based learning activities. In this way, the digital environment served not only as the medium for course delivery but also as the operational setting for collecting pilot evidence later used in the evaluation and refinement process described in this deliverable.

Overall, the implemented parts of the course provided a structured learning pathway linking **technical energy topics**, **deployment planning**, and **regulatory and market considerations** in the context of advanced 5G sustainability. The pilot implementation enabled testing not only

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the coherence of the content and the usability of the Moodle-based format, but also the feasibility of combining quantitative energy-related topics with applied case-study activities and policy-oriented reflection. In this sense, the implemented modules functioned as a practical validation of how sustainability-oriented technical content can be translated into an online learning experience with both analytical and applied value.

3.4.2. Feedback and Observations

This report is based on a total of 25 responses collected through a course evaluation survey. The instrument combines both quantitative ratings, using scale-based questions, and qualitative feedback through open-ended responses.

From a quantitative perspective, the overall trend is clearly very positive. High scores predominate, typically within the 4 to 5 range, with very few negative ratings observed. In addition, responses show a high level of consistency among participants, suggesting a broadly shared perception of the course’s quality. The aspects receiving the highest ratings include the clarity of concept explanations, the relevance of the content—particularly given its focus on current issues such as energy and sustainability—and the overall organization and structure of the course.

Nevertheless, some areas for improvement are identified. These mainly relate to the need for greater depth in certain technical topics, increased opportunities for practical application of the content, and adjustments to the pace in specific sections, which some participants perceive as uneven.

The qualitative analysis reinforces these findings. Participants consistently highlight several strengths, including the usefulness and relevance of the course in the current context of energy and sustainability, the clarity and accessibility of the explanations, and the effectiveness of its introductory approach. The course is widely perceived as well organized and approachable, even for individuals without prior knowledge in the field.

At the same time, recurring criticisms point to certain limitations. Some participants perceive parts of the content as too general, with insufficient technical depth. There is also a clear demand for stronger connections to real-world applications, including concrete examples and case studies. These observations suggest that the course is primarily oriented toward a foundational or outreach-level audience rather than more advanced learners.

In line with these findings, participants propose several improvements. These include incorporating more practical, real-world examples from industry and applied contexts, adding advanced content for learners with prior knowledge, deepening technical and methodological aspects, and placing a greater emphasis on application—particularly in terms of how to implement energy efficiency measures in practice.

In conclusion, the course is very well regarded overall and successfully fulfills its role as an introduction to energy efficiency and sustainability. Its main strengths lie in the clarity of its explanations, the solid structure of its content, and its relevance to contemporary challenges. Its primary limitation is the lack of depth for more advanced profiles, which may reduce its effectiveness for learners seeking a more specialized or technically detailed treatment of the subject.

3.4.3. Refinements and Adjustments

On the basis of the pilot implementation evidence and the feedback collected from participating learners, the refinement strategy for the course on Energy Efficiency and Sustainability in Advanced 5G Technologies should focus on enhancing delivery quality, engagement, and workload transparency while preserving the strong conceptual foundation and relevance of the

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course. The available data indicate that the course is well-structured, coherent, and aligned with current technological and sustainability trends, and therefore does not require major structural redesign. Instead, the refinement approach prioritises improvements in usability and pedagogical effectiveness within the existing four-module architecture.

A first area of refinement concerns **audiovisual delivery and presentation quality**. Although the clarity of explanations is highly rated, feedback suggests that engagement could be improved by revising narration style and enhancing the visual quality of learning materials. In the refined version, efforts will be made to improve narration flow, pronunciation, and overall delivery, including reducing reliance on monotonous audio where present. In parallel, slide design and visual presentation will be revised to reduce text density and improve readability. This includes simplifying complex diagrams, improving graphical consistency, and ensuring that visual elements support rather than overload the learning process.

A second refinement line focuses on **strengthening practical engagement and applied learning**. While the course already includes case studies and applied components, learners indicate the need for more guided examples and structured practice opportunities. To address this, additional short, practice-oriented tasks and step-by-step examples will be integrated across modules, particularly in technically demanding sections. These additions will aim to reinforce the connection between theoretical concepts and real-world applications, especially in areas such as energy optimisation, renewable integration, and sustainability assessment.

A third area concerns **workload transparency and balance.** Implementation evidence shows that certain units exceeded their initially planned workload, contributing to perceptions of density and effort. In response, the refined course will provide clearer guidance on expected time investment and improve the balance between lectures, readings, quizzes, and applied tasks. This will include streamlining overly dense sections, reducing unnecessary repetition, and ensuring that learning activities are proportionate to the 2 ECTS allocation.

Another important refinement dimension relates to **course coherence and closure**. Although the course structure is generally clear, the addition of a final integrative activity will be considered to consolidate learning across modules and strengthen the overall learning pathway. Such an activity will support synthesis of technical, environmental, and policy-related knowledge developed throughout the course.

Further refinements will address **content presentation and sequencing in the earlier modules**. Some materials, particularly in Modules 1 and 2, will be reworked to improve clarity, reduce textual overload, and enhance the flow of explanations. In addition, more explicit and context-rich examples will be introduced to support comprehension and maintain learner attention. At the module level, minor adjustments will also be made to improve internal workload distribution. This includes fine-tuning the balance between units where implementation data indicate higher-than-expected effort.

The refinement strategy will also ensure that accessibility and consistency of learning resources are maintained across all modules. This includes improving alignment between videos, slides, transcripts, and assessment components to support different learning preferences. Overall, the planned refinements aim to build on a course that is already perceived as relevant, coherent, and pedagogically sound. The focus is therefore on enhancing engagement, improving usability, and ensuring a more balanced and accessible learning experience. By addressing these areas, the refined course is expected to provide a more effective integration of technical knowledge, sustainability concepts, and applied skills. At the same time, it will maintain its strong alignment with the objectives of the 5G-DiGITs curriculum and its emphasis on green and energy-efficient 5G technologies.

In conclusion, the refinement strategy seeks to transform a highly relevant and well-evaluated course into a more engaging, learner-friendly, and pedagogically optimised learning experience

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without altering its core academic structure. On the basis of the pilot implementation evidence and the feedback collected from participating learners, the refinement strategy for the course on Energy Efficiency and Sustainability in Advanced 5G Technologies should focus on enhancing delivery quality, engagement, and workload transparency while preserving the strong conceptual foundation and relevance of the course. The available data indicate that the course is well-structured, coherent, and aligned with current technological and sustainability trends, and therefore does not require major structural redesign. Instead, the refinement approach prioritises improvements in usability and pedagogical effectiveness within the existing four-module architecture.

Scope	Refinement area	Adjustment
Whole course	Audiovisual delivery	Improve narration quality, enhance clarity and flow, and reduce reliance on monotonous or AI-generated audio where present
Whole course	Slide and visual design	Reduce text density, improve layout clarity, and enhance visual consistency and readability
Whole course	Practical engagement	Introduce additional guided examples and short practice-oriented tasks across modules
Whole course	Course coherence and closure	Add a final integrative activity to consolidate learning across modules
Whole course	Workload transparency	Clarify expected effort and improve balance between lectures, readings, quizzes, and applied activities
Modules 1–2	Content presentation and sequencing	Rework dense or text-heavy materials, improve explanation flow, and enhance readability
Modules 1–2	Engagement and examples	Introduce clearer real-world examples and more guided explanations
Module 3	Practical consolidation	Maintain structure while strengthening applied case-based learning components
Modules 2–4	Workload balancing	Fine-tune workload distribution across units to better align with the 2 ECTS framework

Table 5. Summary of refinement actions

3.5. Entrepreneurship and Innovation in Advanced 5G Technologies

3.5.1. Course Implementation

Module 1: From Ideas to Opportunities – Innovation in the 5G Landscape

Module 1, "From Ideas to Opportunities – Innovation in the 5G Landscape", was implemented as an introductory module that supports learners in turning early 5G-related ideas into opportunity-oriented concepts grounded in real needs and viable ecosystem contexts. It is

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organised into two units that together build both a human-centred innovation mindset and a strategic view of how 5G ideas can evolve within complex multi-stakeholder environments.

Unit 1.1 "Recognizing Innovation Opportunities in 5G" familiarises learners with Design Thinking as a foundational approach for 5G innovation, highlighting why human-centred methodologies are essential for translating advanced network capabilities into meaningful solutions. Through empathy-focused activities, problem-definition exercises, ideation and rapid prototyping steps, and examples from sectors such as healthcare, manufacturing and smart cities, learners practice moving from initial ideas to more structured solution concepts that leverage features like ultra-low latency, edge computing and massive IoT connectivity. The unit's implementation combined explanatory materials, tools and templates, self-evaluation quizzes and individual and group assignments, fostering a user-first perspective when conceiving 5G innovations.

Unit 1.2 "Validating Ideas through User Research and MVP Testing" introduces learners to open innovation and 5G ecosystem collaboration as critical enablers for transforming ideas into opportunities that can be realised in practice. Framed by open-innovation theory and European ecosystem strategies, the unit presents 5G as a collaborative, multi-actor environment in which operators, vendors, cloud providers, startups, research organisations, vertical industries and regulators jointly create value. Learners engaged with stakeholder-mapping, collaboration-model and partnership-strategy tools, as well as real cases (such as coordinated 5G ecosystem initiatives), to understand how cross-sector cooperation, shared knowledge and structured partnerships can accelerate 5G deployment and turn promising ideas into robust entrepreneurial opportunities.

Module 2: Building & Funding a 5G Startup

Module 2 introduces the key entrepreneurial concepts required to develop and grow startups within the 5G ecosystem. It first focuses on how innovative ventures can design viable business models for 5G-enabled solutions, highlighting the importance of value propositions, ecosystem partnerships, and platform-based approaches in complex telecommunications markets. Learners are introduced to frameworks such as the Business Model Canvas and Lean Startup methodology to structure and validate their business ideas. The module also examines the financial and commercialization aspects of launching a 5G startup, including funding pathways, investor engagement, and effective go-to-market strategies. Emphasis is placed on understanding enterprise-driven markets, building strategic partnerships, and developing scalable solutions that can successfully compete in the rapidly evolving 5G innovation landscape. This module covers about 32 hours of lecture material through videos, slides and text , exercises and mini projects, hands-on application of different tools, other readings and resources for self-studies.

Unit 2.1 – Business Modelling for 5G-Enabled Startups

This unit expands on the fundamentals of business modelling within the 5G ecosystem, guiding learners through the practical application of entrepreneurial frameworks tailored to the telecommunications sector. The unit explains how capabilities such as network slicing, ultra-low latency communication, and massive IoT connectivity enable new digital services and platform-based ecosystems that extend beyond conventional telecom value chains. Learners are introduced to the theoretical foundations of business modelling using established frameworks such as the Business Model Canvas, while exploring how these approaches must be adapted to address the complex stakeholder environments of 5G markets, where collaboration with mobile network operators, hyperscalers, system integrators, and vertical industry partners is essential. Particular emphasis is placed on the dominance of enterprise-focused B2B2X models and the importance of understanding ecosystem dynamics when designing scalable and sustainable 5G ventures.

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The unit also provides practical guidance on applying the Business Model Canvas to 5G ventures by reinterpreting its nine core building blocks within a multi-sided platform context. Participants examine how value propositions, customer segments, partnerships, and cost structures evolve in telecommunications-driven innovation environments, where key resources include network capabilities, spectrum access, and strategic partnerships. The course further explores emerging monetization strategies within the 5G ecosystem, including network slicing services, API monetization, outcome-based pricing, and usage-based models supported by edge computing. Finally, the unit introduces the Lean Startup methodology as a framework for developing and validating 5G innovations under conditions of technological and market uncertainty. Through concepts such as minimum viable products (MVPs), Build-Measure-Learn cycles, and customer discovery processes, learners gain practical strategies for testing solutions, managing long enterprise adoption cycles, and iteratively refining business models within complex telecommunications ecosystems.

Unit 2.2: Startup Funding & Go-to-Market Strategy

This unit provides learners with a comprehensive understanding of how 5G startups secure funding and successfully bring innovative products and services to market. It introduces the funding landscape specific to the 5G ecosystem, where startups must navigate longer development cycles, high capital requirements, and complex regulatory environments. Participants explore multiple funding pathways—including bootstrapping, venture capital, corporate partnerships, and European innovation funding programs—while examining the challenges faced by European 5G startups, such as the significant funding gap compared to global competitors. The unit also highlights financial planning strategies tailored to deep-tech ventures, including valuation methods, financial modeling approaches, and investor relations management. Through real-world examples of successful 5G companies, learners gain insight into how strategic milestone planning, transparent communication with investors, and strong financial narratives can support sustainable startup growth.

In addition to funding strategies, the unit focuses on designing effective go-to-market (GTM) approaches and scaling strategies within the complex 5G ecosystem. Learners examine how startups transition from product development to market adoption by targeting enterprise customers, validating product–market fit through pilot deployments, and demonstrating measurable return on investment. The course emphasizes the shift from product-centric offerings to integrated solution-based models that address the needs of industries such as healthcare, manufacturing, and smart cities. Finally, the unit explores scaling through ecosystem partnerships with telecom operators, cloud providers, and system integrators, highlighting how collaborative innovation initiatives and platform-based approaches can accelerate market expansion. By the end of the unit, participants understand how funding strategies, market positioning, and strategic partnerships work together to support the development and growth of scalable 5G-enabled ventures.

This module combines theoretical instruction with practical engagement to support a comprehensive learning experience. Alongside lectures and conceptual materials, learners are encouraged to apply key concepts through a range of practical tools (On TRLs, Startup readiness assessment, Business Model Canvas, MVP Canvas), guided exercises, and self-assessment quizzes. These activities enable participants to actively engage with topics such as business modelling, funding strategies, and go-to-market planning. In addition, learners are provided with curated readings, guides, and supplementary resources for independent study, allowing them to deepen their understanding and further develop practical entrepreneurial skills.

Module 3: IP, Compliance, and Competitive Positioning in 5G Ventures

Module 3, "IP, Compliance, and Competitive Positioning in 5G Ventures", was implemented as a two-unit module designed to help learners understand how intellectual property, regulatory

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and standards compliance, and strategic positioning shape the success of 5G and Beyond 5G ventures. It connected legal–regulatory awareness with market-oriented thinking, so that participants could design ventures that are both compliant and competitively differentiated within complex 5G ecosystems.

Unit 3.1 "Intellectual Property and Tech Transfer in Telecom & Digital" focuses on core intellectual-property and compliance dimensions relevant to deep-tech and telecommunications innovation, including how different IP mechanisms (such as patents and know-how) interact with 5G standardisation, licensing, and interoperability requirements. Learners are introduced to key regulatory and standards bodies, typical compliance obligations in advanced network deployments, and the implications of spectrum policy, security, and data-protection requirements for 5G business design. Through explanatory materials and applied examples, the implementation highlights how early IP and compliance planning can reduce risk, protect innovation outcomes, and support the sustainable growth of 5G ventures.

Unit 3.2 "Compliance, Ethics, and Responsible Scaling" addresses competitive positioning in 5G and Beyond markets, linking compliance-ready offerings to marketing and go-to-market strategies. Building on concepts such as technology adoption lifecycles, segmentation–targeting–positioning, and ecosystem-centric strategies, the unit shows learners how to translate 5G technical capabilities into differentiated value propositions for specific verticals and stakeholder groups. Learners work with templates, cases and exercises on positioning, messaging, and partner-driven go-to-market approaches, gaining practical skills to ensure that compliant, IP-aware 5G solutions can stand out in competitive markets and achieve sustainable adoption.

Overall the course introduces learners to key concepts of technology-driven entrepreneurship, innovation processes, and business modelling in the context of advanced 5G and Beyond 5G applications, with particular emphasis on digital and green transition opportunities. The course was organised into modular units that blended conceptual content with case examples and practical exercises, enabling participants to connect technical developments in 5G with real-world innovation, start-up creation, and intrapreneurial initiatives across relevant industrial and service sectors.

3.5.2. Feedback and Observations

This report is based on a total of 23 responses collected through a course evaluation survey. The questionnaire combines quantitative ratings, using scale-based questions, with qualitative feedback gathered through open-ended responses.

Overall, the course is well rated, although it exhibits notable variability depending on the student profile. PhD students tend to assign lower ratings, often perceiving the course as too basic or overly theoretical for their needs. In contrast, Master's and Bachelor's students provide significantly more positive evaluations, indicating that the course aligns better with their level and expectations.

From a quantitative standpoint, high ratings clearly predominate. Across most indicators—such as structure, clarity, alignment between components, quality of materials, and overall satisfaction—the most frequent scores fall within the 4 to 5 range. Among non-doctoral students, particularly those at the Bachelor's and Master's levels, evaluations are consistently high with relatively low dispersion. However, responses from PhD students show greater variability, with some expressing concerns about the course's relevance to their research, its theoretical orientation, or the perceived workload.

The most highly rated aspects include the clarity and consistency of the content, the organization and overall structure of the course, and the alignment between modules, activities, and learning objectives. Students also report high levels of interest and overall satisfaction. Case

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studies, when included, are particularly well received and frequently highlighted as useful learning elements.

Despite these strengths, several areas for improvement emerge. Students point to the need for greater practical application and more applied exercises, as well as increased depth in advanced entrepreneurship tools. Some also note inconsistencies in the level of development across modules, with certain units appearing more complete than others. The use of AI-generated voices is frequently criticized for being monotonous and negatively affecting engagement, while the workload is perceived as excessive by some participants.

The qualitative analysis provides further insight into these patterns. Among the main strengths, students consistently describe the course as clear, accessible, and well explained, particularly for those without prior experience. It is also perceived as inspiring and effective in fostering an entrepreneurial mindset. The inclusion of real-world cases, when present, is highly valued, and discussion forums are frequently mentioned as a particularly useful component that enhances collaboration and engagement. Overall, the course is seen as well structured and logically organized, although this perception is not shared equally across all profiles.

At the same time, several recurring weaknesses are identified. A common criticism is the lack of practical depth, with students noting an overemphasis on theoretical content and a limited number of applied exercises. Some participants—especially those with prior experience in 5G or advanced research—perceive the content as too generic. Organizational inconsistencies between modules are also reported, with specific references to difficulties in navigating materials in certain units. The use of AI-generated narration is again highlighted as a drawback, described as monotonous and detrimental to sustained attention. Additionally, some students mention a high workload and a lack of coherence or contextualization in certain topics.

Participants propose a number of improvements to address these issues. Key suggestions include incorporating more real and applied case studies, introducing practical tools such as the Business Model Canvas, idea validation methods, and startup-oriented exercises, and improving the structure and coherence of modules—particularly in terms of file organization and navigation. Students also recommend replacing or complementing AI-generated narration with human delivery, increasing the number of practical and interactive activities, and achieving a better balance of workload across modules.

In conclusion, the course is very well regarded overall, particularly among Master's and Bachelor's students, who represent its most appropriate target audience. Its main strengths include a motivational and engaging approach, clarity of content, a generally well-defined structure, effective use of case studies when included, and suitability for learners without prior experience. However, several limitations remain, notably the lack of a deeper practical component, the perception of being too basic for more advanced profiles, certain issues in the organization of materials, and the negative impact of AI-generated voices on the learning experience.

3.5.3. Refinements and Adjustments

On the basis of the pilot evidence, the refinement strategy for **Entrepreneurship and Innovation in Advanced 5G Technologies** should aim to **preserve the current course as a strong introductory-level offering while expanding the curriculum with an advanced-level course that addresses the needs of learners seeking greater depth and applied challenge**. The available data do not suggest that the existing course is failing its target audience. On the contrary, the feedback confirms that the course is well regarded among Master's and Bachelor's students, who represent its most appropriate learner profile. The pilot evidence therefore supports a dual-track refinement approach: consolidating and optimising the current introductory course on the one hand, and designing a more demanding advanced-level companion course on the other.

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This direction is consistent with the original course rationale in D2.2, where the course was conceived as a foundational entrepreneurship and innovation offer for learners entering the 5G ecosystem from diverse educational and professional backgrounds.

A first refinement line concerns **the introductory course: consolidation and delivery improvement**. The pilot results confirm that the current course performs well in terms of structure, clarity, motivational impact, and suitability for learners without prior entrepreneurship experience. The most actionable improvement in this track concerns the audiovisual delivery. The use of AI-generated narration is identified as a recurring source of reduced engagement across the pilot cohort, particularly for learners who find the monotonous delivery detrimental to sustained attention. In the refined version, narration scripts should be revised to improve naturalness and pacing, and, where feasible, the AI-generated voice should be replaced or substantially complemented with human delivery. In parallel, the course already performs positively in terms of case studies and discussion forums, and these components should be retained and, where possible, extended. The presence of real-world examples and interactive elements is consistently reported as a strength, and this emphasis should be reinforced in the refined version.

A second refinement line concerns **practical depth and applied engagement within the introductory course**. Although the course already includes practical tools and frameworks, the pilot feedback shows that some learners — particularly those with prior experience — would benefit from more applied exercises and a stronger theory-practice connection. In the refined version, this should be addressed by reinforcing the practical scaffolding already present in the course, particularly around business modelling frameworks such as the Business Model Canvas, the Lean Startup methodology, and idea validation tools. Rather than introducing entirely new components, the aim should be to make the application of these frameworks more explicit and more guided, through additional worked examples, annotated templates, and structured mini-tasks that allow learners to practise applying concepts to realistic 5G entrepreneurship scenarios. This will address the recurring learner request for more applied content without altering the introductory character of the course.

A third refinement line concerns **module-level consistency and organisation**. The pilot feedback identifies organisational inconsistencies between modules, including difficulties in navigating materials in certain units and a perception that some units are less fully developed than others. In the refined version, the course should be reviewed to ensure a more consistent level of material development, clearer file organisation within the learning management system, and more uniform navigation logic across units. This will improve the overall learner experience without requiring substantive content changes and will directly address one of the more specific weaknesses identified in the qualitative feedback.

A fourth refinement line concerns **the design of a new advanced-level course**. The pilot evidence reveals a consistent pattern of feedback from more experienced learners — particularly PhD students — who find the current course too basic or too generic for their level. This is not a weakness of the introductory course itself, but rather a signal that a complementary advanced offering is needed within the 5G-DiGITs curriculum. The advanced course should be designed to move beyond foundational concepts and focus instead on complex real-world cases, more sophisticated business modelling approaches (including Lean Startup, Jobs-to-be-Done, and advanced validation methods), detailed financial modelling and funding strategy, and practical workshops and simulations that require learners to take entrepreneurial decisions under realistic constraints. The course should also address responsible scaling and launch strategy in the 5G context, connecting innovation management with the regulatory, ethical, and competitive dimensions already introduced elsewhere in the curriculum. Where feasible, the advanced course should incorporate human narration from the outset, given the consistent

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feedback across the pilot cohort on the limitations of AI-generated delivery for sustained engagement.

Taken together, these preliminary refinements support a clear course-level conclusion: **Entrepreneurship and Innovation in Advanced 5G Technologies should remain a focused introductory course with targeted delivery improvements, while a new advanced-level companion course should be developed to meet the needs of more experienced learners**. The evidence does not justify a redesign of the existing course identity; it justifies a more complete curriculum architecture that preserves the introductory course's strengths while creating a more demanding advanced pathway for learners who are ready to engage with entrepreneurship and innovation in greater depth.

Scope	Refinement area	Adjustment
Introductory course	Audiovisual delivery	Revise narration scripts, improve pacing and naturalness, and replace or substantially complement AI-generated voice with human delivery where feasible
Introductory course	Practical scaffolding	Reinforce application of BMC, Lean Startup, and idea validation tools through worked examples, annotated templates, and structured mini-tasks in realistic 5G scenarios
Introductory course	Module consistency and LMS organisation	Review and equalise the level of development across units; improve file organisation and navigation logic within the LMS
Advanced-level course	Business modelling depth	Design advanced modules covering BMC, Lean Startup, Jobs-to-be-Done, advanced validation methods, and financial modelling for 5G ventures
Advanced-level course	Workshops and simulations	Include complex real-world case studies and decision-based simulations requiring learners to apply entrepreneurial judgement under realistic 5G constraints
Advanced-level course	Responsible scaling and launch strategy	Address launch strategy, responsible scaling, and the regulatory and ethical dimensions of 5G innovation, connecting to the broader curriculum framework
Advanced-level course	Audiovisual delivery	Incorporate human narration by design from the outset, given the consistent pilot feedback on the limitations of AI-generated delivery for sustained learner engagement

Table 6. Summary of refinement actions

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3.6. Digital Skills for Beyond 5G Technologies

3.6.1. Course Implementation and Pilot Context

The course **Digital Skills for Beyond 5G Technologies** was developed within the 5G-DiGITs curriculum to strengthen advanced digital competences related to Beyond 5G systems. According to the curriculum design defined in D2.2, the course carries **2 ECTS** and a total workload of **60 hours**, and is primarily intended for learners in **ICT and engineering-related fields**, including students at **Bachelor's, Master's, and PhD level**, as well as early-career professionals seeking advanced 5G-related competences. The course is structured into three thematic modules:

- Module 1: Advanced digital skills for working with 5G technologies
- Module 2: Machine learning, AI integration, and data analytics in 5G
- Module 3: Cybersecurity challenges and solutions in 5G networks

Module 1 (Advanced digital skills for working with 5G technologies)

Within the overall course framework, **Module 1 addresses the foundational digital competencies required to understand and work with 5G and Beyond 5G (B5G) technological environments**. It contributes to learning outcomes related to explaining the evolution from 5G to Beyond 5G technologies, understanding the architecture and key operational components of modern telecommunications networks, and applying data visualisation tools to interpret and communicate real-time network performance metrics. In the Moodle implementation, this module was organised into two units:

- Unit 1.1: Introduction to 5G Technologies
- Unit 1.2: Data Analytics and Visualisation in 5G Networks

Together, these units were designed to develop a coherent introduction to the technological and analytical foundations necessary for working with 5G systems. While Unit 1.1 focuses on the conceptual and architectural principles underpinning modern telecommunications infrastructures, Unit 1.2 introduces learners to the role of data analytics and visualisation techniques in monitoring, analysing, and optimising network performance.

Unit 1.1 introduced the core technological concepts associated with 5G and Beyond 5G ecosystems. The unit was divided into several lesson-level sections covering the evolution of mobile communication technologies from previous generations to 5G and B5G, the fundamental architecture of 5G networks, including key components and service layers, and the role of enabling technologies such as network slicing, spectrum management, and virtualised network infrastructures. Additional sections addressed the integration of 5G with emerging digital ecosystems, including IoT and edge computing environments, as well as the growing importance of energy-efficient networking approaches in modern telecommunications infrastructures.

Unit 1.2 built upon these conceptual foundations by introducing learners to data-driven approaches for monitoring and optimising network operations. The lessons in this unit focused on the role of data analytics in telecommunications systems, the interpretation of network performance indicators, and the use of data visualisation techniques to communicate complex operational metrics. Particular attention was given to the role of dashboards and visual analytics tools in supporting real-time network monitoring and decision-making processes within 5G infrastructures. The unit also explored the relevance of data-driven insights for improving network efficiency, detecting anomalies, and supporting optimisation strategies in dynamic network environments.

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Each lesson in this implemented module followed a consistent pedagogical format. Learners were provided with a video presentation, the corresponding presentation slides with speaker notes available as transcript-style support material, a list of references for further reading, and a self-evaluation quiz designed to reinforce the lesson's key concepts. These quizzes were used as formative learning tools and, in many cases, included hints or explanations to support autonomous learning and self-checking. This format was intended to support asynchronous, self-paced study while ensuring consistency across the module's sections and strengthening aspects later addressed in the pilot evaluation, such as course organisation, clarity of learning materials, digital learning experience, and assessment usefulness.

In line with the implementation approach adopted across the course contributions, each unit also incorporated a problem-based learning component. At the end of Unit 1.1, learners were introduced to the case study "Case Study - Exploring the Digital Tools Behind 5G Smart Services (Unit 1.1)". This comprehensive case study is aiming at exploring how digital tools enable real-time monitoring, visualization, and decision-making in 5G-enabled urban ecosystems.

At the end of Unit 1.2, a second case study, "Case Study – Designing Dashboards to monitor 5G network performance (Unit 1.2)" is presented. The activity explores how dashboards transform complex 5G network data into actionable insights for smart city applications. This implementation logic is consistent with the broader PBL orientation of the curriculum defined in D2.2 and D2.3 and was intended to support practical application, authenticity of learning tasks, self-directed investigation, and the transfer of knowledge to realistic technological contexts.

The workload of Module 1 was monitored using the workload calculation methodology applied to the implemented units, distinguishing between lecture hours, exercise hours, and self-study hours. For Unit 1.1, the initially planned workload was 10 hours. The implemented version included lecture materials, supporting readings, self-evaluation quizzes, and the PBL case-study activity, leading to a workload distribution combining lecture-based learning with guided exercises and independent study. For Unit 1.2, the initially planned workload was also 10 hours, with a learning pathway that combined conceptual explanations of data analytics techniques with applied exercises and the development of a visualisation-based case study. Workload monitoring was based on the duration of lesson videos, the estimated time required for quizzes and exercises, the review of presentation materials, and the completion of the case-study tasks. This monitoring process formed part of the pilot evidence base used to evaluate the adequacy of the learning pathway and to identify potential improvements for the refined curriculum version.

Overall, Module 1 was implemented as an introductory learning block designed to provide learners with both conceptual understanding of 5G technologies and the analytical tools necessary to interpret network performance data. The pilot implementation allowed the project partners to test whether the combination of lesson-based resources, formative assessment tools, and problem-based learning activities could effectively support the transition from foundational knowledge acquisition to early-stage analytical practice in a telecommunications context. As such, the module played a central role in establishing the technological and analytical foundations upon which the subsequent modules of the course build.

<u>**Module 2 (Machine learning, AI integration, and data analytics in 5G)**</u>

Within the overall course framework, **Module 2 addresses the application of machine learning, artificial intelligence, and advanced data analytics techniques within 5G and Beyond 5G technological environments**. It contributes to learning outcomes related to analysing telecom data using advanced analytics methods, implementing machine learning algorithms for network

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optimisation, and integrating cloud, AI, and edge computing technologies to support intelligent 5G applications. In the Moodle implementation, this module was organised into two units:

- Unit 2.1: Machine Learning and AI in 5G Networks
- Unit 2.2: Advanced Data Analytics Techniques in 5G

Together, these units were designed to develop learners' understanding of how artificial intelligence and data analytics technologies can support the optimisation, automation, and intelligent management of modern telecommunications networks.

Unit 2.1 introduced the conceptual foundations of machine learning and artificial intelligence in the context of 5G systems. The lessons within this unit addressed the role of data-driven approaches in telecommunications network management, including predictive maintenance, traffic optimisation, and dynamic resource allocation. Additional lesson sections explored the types of machine learning models used in network optimisation, the role of training data in telecommunications contexts, and the potential benefits and limitations of AI-driven decision-making in complex network environments. Through this structure, the unit aimed to familiarise learners with the key principles underpinning intelligent network management systems.

Unit 2.2 built on these foundations by introducing more advanced data analytics techniques applied to telecommunications datasets. This unit focused on the use of machine learning algorithms to analyse real-time telecom data streams, detect anomalies in network performance, and generate predictive insights capable of supporting network optimisation strategies. The lessons also addressed the visualisation and interpretation of machine learning outputs, emphasising how analytical insights can be translated into operational decisions for network management. The unit therefore provided a bridge between theoretical AI concepts and the practical use of analytics tools for telecommunications monitoring and diagnostics.

As in the other modules of the course, each lesson in the implemented module followed a consistent pedagogical format. Learners were provided with a video presentation, the corresponding presentation slides with speaker notes serving as transcript-style support material, recommended references for further reading, and a self-evaluation quiz designed to reinforce the lesson's key concepts. These quizzes functioned as formative learning activities and frequently included hints or feedback explanations in order to support autonomous learning and self-assessment. This consistent structure supported asynchronous participation and helped maintain a coherent digital learning experience across the module.

In line with the pedagogical design of the overall curriculum, both units also incorporated problem-based learning activities designed to promote applied reasoning and the practical use of data analytics tools. At the end of Unit 2.1, learners were introduced to the case study "Using Machine Learning to detect traffic patterns in 5G Networks" which required them to explore how AI transforms network monitoring and optimization in modern telecommunications. Same happens with unit 2.2, where at its end, we present the students the case study "Data visualization dashboard for Smart City KPIs", learners were asked to work with datasets derived from smart city sensor systems, including traffic, energy consumption, and environmental monitoring data. The task required them to construct an interactive dashboard capable of presenting key performance indicators in an interpretable format and to reflect on how such visual analytics tools can support real-time decision-making in urban digital infrastructures. The Moodle platform served as the central environment for presenting the PBL scenarios, distributing datasets and supporting materials, and enabling learners to submit their project deliverables. This structure reinforced the curriculum's emphasis on practical, problem-oriented learning and supported the transfer of analytical skills to realistic technological contexts.

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The workload of Module 2 was monitored using the same methodology applied across the course implementation, distinguishing between lecture hours, exercise hours, and self-study hours. For Unit 2.1, the planned workload was 10 hours, combining lecture materials with analytical exercises and the PBL case-study component. Unit 2.2 was planned as a shorter but more technically focused unit with a workload of approximately 5 hours, emphasising hands-on data analysis and visualisation tasks. Workload calculations were based on the duration of lesson videos, estimated completion time for quizzes and exercises, the review of supporting materials, and the completion of the PBL activities. Monitoring these values during the pilot phase allowed partners to evaluate whether the learning pathway remained consistent with the expected ECTS-based workload and to identify areas where adjustments might improve the balance between conceptual explanation and practical application.

Overall, Module 2 was implemented as a technically oriented learning block focused on the application of artificial intelligence and advanced analytics techniques within 5G systems. By combining conceptual explanations of machine learning principles with applied problem-solving activities, the module aimed to help learners develop the analytical competencies necessary to work with intelligent telecommunications infrastructures. The pilot implementation therefore provided valuable evidence on whether the integration of AI-related learning materials, self-evaluation activities, and real-world case studies could effectively support the development of advanced digital skills aligned with the broader objectives of the 5G-DiGITs curriculum.

Module 3 (Cybersecurity challenges and solutions in 5G networks)

Within the overall course framework, **Module 3** addresses the cybersecurity dimension of 5G and Beyond 5G environments. It contributes to learning outcomes related to evaluating cybersecurity risks in 5G infrastructures, applying mitigation strategies based on encryption, authentication, and Zero Trust approaches, and designing secure, industry-compliant 5G architectures for real-world scenarios. In the Moodle implementation, this module was organised into two units:

- Unit 3.1: Fundamentals of Cybersecurity in 5G Networks
- Unit 3.2: Advanced Cybersecurity Solutions for 5G

Together, these units were designed to develop both foundational and advanced cybersecurity competencies for 5G systems.

Unit 3.1 introduced the core principles of cybersecurity in 5G systems. It was divided into seven lesson-level sections covering cybersecurity fundamentals, the expanded attack surface and risk shift introduced by 5G, risk management and cybersecurity strategy, security controls and countermeasures, detection and incident response, data protection and privacy, and human factors and security awareness.

Unit 3.2 built on this foundation by addressing more advanced topics, including 5G security architecture and **Zero Trust** models, cryptography and identity management, detection and response, and securing 5G endpoints and operations. This organisation ensured a progressive learning sequence from conceptual foundations to more applied and architecture-oriented security topics.

Each lesson in this implemented module followed a consistent pedagogical format. Learners were provided with a **video presentation**, the corresponding **presentation slides with speaker notes available as transcript-style support material**, a list of **references for further reading**, and a **self-evaluation quiz** designed to reinforce the lesson's key concepts. These quizzes were used as **formative learning tools** and, in many cases, included hints or explanations to support autonomous learning and self-checking. This format was intended to support asynchronous, self-paced study while ensuring consistency across the module’s sections and strengthening

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aspects later addressed in the pilot evaluation, such as **course organization**, **quality of learning materials**, **digital learning experience**, and **assessment usefulness**.

In line with the implementation approach adopted across the course contributions, each unit also included a **problem-based learning component**. At the end of **Unit 3.1**, learners were introduced to the case study **"Cybersecurity Risk Analysis in 5G Smart Cities,"** structured around architecture analysis, threat modelling, risk communication, and a practical task. At the end of **Unit 3.2**, a second case study, **"Securing 5G Endpoints and Operations,"** combined explanatory material with a practical exercise requiring learners to analyse simulated service-performance data, identify anomalies, and propose appropriate response measures. Moodle served as the central environment for presenting the PBL materials, providing access to supporting resources, and enabling the submission of final deliverables. This implementation logic is consistent with the broader PBL orientation of the curriculum defined in D2.2 and D2.3 and was intended to support **practical application**, **authenticity of learning tasks**, **self-directed investigation**, and **the transfer of knowledge to realistic contexts, as** reflected in the pilot feedback instrument.

The workload of Module 3 was monitored using the workload calculation methodology applied to the implemented units, distinguishing between **lecture hours**, **exercise hours**, and **self-study hours**. For **Unit 3.1**, the initially planned workload was **10 hours**, while the implemented workload reached **13 h 14 min**. This final value comprised approximately **5 h 42 min of lecture time**, **3 h 10 min of exercise time**, and **4 h 26 min of self-study time**, including both the regular lesson materials and **PBL-related components**. For **Unit 3.2**, the initially planned workload was **15 hours**, whereas the actual workload was 15 h 57 min, including approximately **6 h 13 min of lecture time**, **3 h 48 min of exercise time**, and **5 h 18 min of self-study time**. These calculations were based on the effective duration of lesson videos, PBL lecture materials, self-evaluation quizzes, PBL exercises, presentation slides with speaker notes, and recommended references included in the materials. The monitoring showed that Unit 3.1 exceeded the initially planned workload, while Unit 3.2 remained close to the original estimate; however, some internal balancing between the two units may still be considered in the refined version. This workload monitoring also formed part of the pilot evidence base used to assess the adequacy of the learning pathway and to identify areas requiring refinement.

Overall, Module 3 was implemented as a specialized learning block designed to move learners from **foundational cybersecurity concepts** towards more **advanced security architectures and applied problem-solving scenarios** in 5G environments. The pilot version was particularly valuable for testing whether a modular sequence of lesson-based resources, self-evaluation activities, and case-study tasks could support both conceptual understanding and practice-oriented reasoning in a cybersecurity context. This made the implementation relevant not only as a content delivery exercise, but also as a validation of the pedagogical suitability of the module for advanced digital-skills training in Beyond 5G technologies.

3.6.2. Feedback and Observations

The pilot feedback collected for the course **Digital Skills for Beyond 5G Technologies** indicates an overall positive assessment of the course, while also highlighting several specific issues affecting delivery quality, learner engagement, and the balance between theory and application. A total of **29 valid responses** were reviewed, corresponding to **18 Master students, 7 PhD students, and 4 Bachelor students**. Overall, the results confirm that the course is perceived as relevant and generally well-structured, but they also show that some aspects of the learning experience require refinement to better support engagement, practical application, and consistency across modules. The course itself combines advanced 5G digital skills, AI/data analytics, and cybersecurity.

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A review of the quantitative results shows that the strongest dimensions are **relevance to current trends** and **structure and organization**, both with an average score of **4.31/5**. These are followed by **fit to learner profile** (**4.00/5**), **knowledge and skills improvement** (**3.93/5**), **quality and alignment of materials** (**3.90/5**), and **theoretical foundation** (**3.97/5**). The PBL-related items also perform positively, with **case study usefulness, reflection, and transfer all scoring 3.97/5, suggesting** that the course's problem-based components are broadly valued by learners. These findings are consistent with the original design of the course, which was conceived as a structured, modular, and practice-oriented learning pathway combining lectures, case-based work, practical exercises, and self-directed study.

The weakest area in the dataset is **engagement and satisfaction**, with an average of **3.31/5**, clearly below the rest of the evaluation dimensions. Other comparatively weaker dimensions are **assessment usefulness**, **digital tools integration**, and **teaching methodology**, all at **3.66/5**, as well as **theory-practice connection** at **3.69/5**. This pattern is important because it shows that the main issue is not the perceived relevance or academic legitimacy of the course content, but rather how some parts of that content are delivered and experienced by learners. In other words, the feedback points more strongly to a **pedagogical and presentation problem** than to a fundamental content-design problem. This interpretation is also consistent with the broader methodological expectations of the curriculum, which were explicitly intended to combine theoretical grounding with applied, problem-based, and interactive learning approaches.

The qualitative feedback reinforces this interpretation. The most recurrent positive themes are that the course is **well organized**, **easy to follow**, and **relevant** for learners seeking a structured introduction to advanced digital skills in the Beyond 5G domain. Several comments also value the inclusion of case studies and short reflective activities, especially when manageable in size and clearly connected to the learning material. At the same time, the main critical patterns are highly consistent: learners report that some materials are **too text-heavy**, that the **AI-generated narration reduces attention and engagement**, that the pronunciation of abbreviations and technical terms is sometimes unclear, and that the course will benefit from **more guided practical examples** and **clearer visual support**. A further recurring observation is that the course can feel **dense** or somewhat **heavy for a 2 ECTS offering**, particularly when the learner does not already have a strong technical background.

A particularly important observation emerging from the open comments is that not all weaknesses appear to affect the course uniformly. One of the clearest qualitative responses explicitly distinguishes between the modules and states that **Module 3 (cybersecurity)** is substantially stronger than **Modules 1 and 2**, which were described as weaker in clarity, audiovisual presentation, and overall quality. This distinction matters for interpreting the course-level feedback.

From an evaluation perspective, the pilot yields three main conclusions. First, the course is **pedagogically viable and relevant**, especially as an introductory-to-intermediate digital skills course in the Beyond 5G area. Second, the course will clearly benefit from **stronger practical scaffolding**, **better audiovisual delivery**, and **lighter, more engaging presentation formats**. Third, the findings should be interpreted with **caution at the module level**, as the qualitative evidence suggests that the cybersecurity component performed better than some earlier modules. This is important for refinement planning because it implies that some improvements should be conceived at a full-course level, while others should be framed as more targeted, incremental improvements rather than as a wholesale redesign of a specific module.

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3.6.3. Refinements and Adjustments

Based on the pilot evidence, the refinement strategy for Digital Skills for Beyond 5G Technologies focuses primarily on improving delivery quality, strengthening guided practical engagement, and clarifying module-level differentiation, rather than fundamentally redefining the course objectives. The quantitative results do not indicate rejection of the course concept; rather, they confirm that learners see the course as relevant, well-structured, and theoretically meaningful. The required refinements, therefore, concern how the content is operationalized in the LMS and how effectively the learning resources support sustained attention, comprehension, and transfer to applied scenarios. This direction is fully aligned with the original design principles of the curriculum, which combined modular organization, digital delivery, case-based learning, and problem-based activities intended to promote applied competencies in Beyond 5G contexts.

A first refinement line concerns the **audiovisual and presentational quality of the learning materials**. The pilot feedback shows that the AI-generated narration is one of the clearest sources of reduced engagement. In the refined version of the course, this should be addressed by revising the narration scripts, removing unresolved placeholders or unnatural phrasing, improving the pronunciation of abbreviations and technical terms, and, where feasible, replacing or complementing the current AI-generated voice with improved narration. In parallel, slides should be revised to reduce text density, improve visual hierarchy, eliminate blurred or poorly rendered visual elements, and strengthen the explanatory function of figures, diagrams, and examples. These actions are expected to improve the weakest-rated dimension of the pilot, namely engagement and satisfaction, without altering the overall course structure.

A second refinement line concerns the **strengthening of practical guidance and theory-practice integration**. Although the case-study and PBL dimensions were evaluated positively overall, the feedback still indicates a need for more guided practical content and clearer applied examples. For this reason, the refined course should reinforce short applied tasks within the modules, especially through structured examples that show how theoretical concepts are translated into analysis, design, or decision-making in realistic 5G scenarios. For example, for the cybersecurity module, this can be achieved by further emphasizing guided exercises around threat identification, security architecture choices, anomaly detection, incident response, and the use of reference frameworks and tools already aligned with the course's case-study ecosystem. In this respect, the current case-study framework developed for the Digital Skills course provides a suitable basis for refinement, since it already connects cybersecurity, analytics, visualization, and intelligent 5G network management in realistic settings.

A third refinement line concerns the **overall balance and coherence of learner workload**. The pilot comments show that some learners perceive the course as dense for a 2 ECTS offer. This issue is especially relevant in light of the implementation monitoring already documented for Module 3, where Unit 3.1 exceeded the initial workload estimate, and Unit 3.2 remained close to the original plan. In the refined version, minor workload rebalancing should therefore be considered, particularly by simplifying overly dense explanatory sequences, making expected effort more transparent, and ensuring that the amount of reading, audiovisual material, quiz activity, and applied work remains proportionate to the intended learning hours. For example, for the cybersecurity module (Module 3), this should be framed as an **internal balancing refinement** rather than a structural reduction of the cybersecurity component, since the evidence does not suggest that Module 3 is the main source of dissatisfaction.

A fourth refinement line concerns the **course-level coherence of the learner journey**. One useful suggestion emerging from the qualitative feedback is the addition of a short final integrative task that helps learners consolidate the course as a whole, rather than reflecting only at the

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module level. In practice, the refined version could therefore include a light final synthesis activity, such as a short reflective assignment, a compact cross-module quiz, or a concluding task requiring learners to connect 5G architecture, data/AI, and cybersecurity dimensions within a single applied scenario. This will improve closure, strengthen coherence across the three modules, and better reflect the interdisciplinary intent of the course design.

Scope	Refinement area	Adjustment
Whole course	Audiovisual delivery	Revise narration scripts, improve pronunciation and flow, and improve or replace AI-based audio where feasible
Whole course	Slide and visual design	Reduce text density, improve figures and layout clarity, and correct blurred, overloaded, or poorly rendered visual elements
Whole course	Practical engagement	Add more guided applied examples and short practice-oriented tasks across the course
Whole course	Course closure	Add a short final integrative activity to consolidate learning across all modules
Whole course	Workload transparency	Clarify expected effort and improve the balance between videos, readings, quizzes, and applied tasks
Modules 1-2	Content presentation and sequencing	Rework the most text-heavy and repetitive materials, improve slide readability, and simplify lesson flow where clarity and audiovisual quality were perceived as weaker
Modules 1-2	Engagement and examples	Introduce clearer, real examples and more guided explanations to strengthen attention and comprehension in the earlier modules
Module 3	Practical consolidation	Maintain the current structure broadly, while further strengthening guided cybersecurity exercises and case-based application
Module 3	Internal workload balancing	Fine-tune the balance between Unit 3.1 and Unit 3.2 without reducing the practical orientation of the module

Table 7. Summary of refinement actions

3.7. Green Skills for Beyond 5G Technologies

3.7.1. Course Implementation and Pilot Context

The course **Green Skills for Beyond 5G Technologies** was developed within the 5G-DiGITs curriculum to address the environmental, technological, regulatory, and business dimensions of sustainable 5G and Beyond 5G systems. According to the curriculum design, the course carries **2 ECTS** and a total workload of **60 hours**, and is primarily intended for learners in **engineering,**

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ICT, and related technological or environmental fields, including students at **Bachelor's, Master's, and PhD level**, as well as other learners interested in the intersection between telecommunications and green innovation. The course is structured into four thematic modules:

- Module 1: Sustainable Design and Principles in 5G
- Module 2: Circular Economy and Life Cycle Thinking in ICT
- Module 3: Energy Efficiency and Carbon Reduction Strategies
- Module 4: Regulatory, Ethical, and Business Perspectives on Green 5G

Module 1 (Sustainable Design and Principles in 5G)

Within the overall course framework, **Module 1** addresses the foundations of sustainable design in 5G systems. It contributes to learning outcomes related to understanding the fundamentals of sustainable ICT systems and green 5G networks, describing eco-design principles for 5G infrastructure and components, identifying emerging green technologies relevant to 5G deployment, and evaluating the integration of sustainability into 5G system architecture.

In the Moodle implementation, **Module 1** was organised into two units:

- Unit 1.1: Foundations of Green ICT and Emerging Sustainable Technologies
- Unit 1.2: Eco-Design in 5G Networks and Cloud

Unit 1.1 introduced the basic principles of sustainability in ICT and their relevance to 5G systems. It included lesson-level sections on the principles of sustainability in ICT, emerging technologies for green 5G, sustainability challenges in ICT infrastructure, system-level thinking and lifecycle design for green 5G deployment, ICT and environmental life-cycle analysis, and policy drivers shaping sustainable ICT design. The unit concluded with the case study **"Evaluating Green ICT Principles in Network Planning,"** implemented through two video-supported parts, accompanying transcript-style slides, and an assignment exercise.

Unit 1.2 extended this foundation by addressing eco-design principles in 5G networks and cloud environments. Its sections covered eco-design strategies for 5G infrastructure, AI and automation for green network design, sustainable cloud and edge architectures, design thinking for sustainable 5G, sustainability metrics for cloud networks, and visualisation of 5G energy flows. This unit also included a **glossary** resource and concluded with the case study **"Eco-Design of a Sustainable 5G Node,"** structured through two video parts, transcript-supported slide materials, and an assignment exercise.

Each lesson in Module 1 followed a consistent pedagogical format. Learners were generally provided with a **video presentation**, the corresponding **presentation slides with speaker notes used as transcript-style support material**, and a **self-evaluation quiz** to reinforce the lesson's main concepts. This format was designed to support asynchronous, self-paced study while ensuring consistency across the module's sections and strengthening aspects later addressed in the pilot evaluation, such as **course organisation**, **quality of learning materials**, **digital learning experience**, and **assessment usefulness**.

The workload of Module 1 was monitored using the methodology applied to the implemented units, distinguishing between **lecture hours**, **exercise hours**, and **self-study hours**. For **Unit 1.1**, the initially planned workload was **8 hours**, while the implemented workload reached **10 h 50 min**. This final value comprised approximately **3 h 52 min of lecture time**, **3 h 00 min of exercise time**, and **3 h 58 min of self-study time**, including both the regular lesson materials and **PBL-related components**. For **Unit 1.2**, the initially planned workload was **7 hours**, whereas the actual workload was 8 h 24 min, including approximately **2 h 52 min of lecture time**, **2 h 20 min of exercise time**, and **3 h 12 min of self-study time**. These calculations were based on the effective duration of lesson videos, self-evaluation quizzes, case-study lecture materials, assignment exercises, transcript-supported slides, references, and, in the case of Unit 1.2, the additional glossary resource. The monitoring, therefore, showed that both units exceeded their initially planned workloads, suggesting that some internal rebalancing may be considered in the refined version of the module.

In pedagogical terms, Module 1 combined **conceptual instruction**, **formative self-assessment**, and **practice-oriented case-study activities**. The case studies were intended to support **practical application**, **authenticity of learning tasks**, **self-directed investigation**, and **transfer of knowledge to realistic sustainability-oriented contexts**, in line with the broader PBL and case-based orientation of the curriculum.

Module 2 (Circular Economy and Life Cycle Thinking in ICT)

Module 2 explores how ICT products and networks can be designed and managed sustainably across their entire lifecycle. It emphasizes the use of Life Cycle Assessment (LCA) to evaluate environmental impacts and introduces circular economy strategies to reduce waste and resource use. Learners examine materials, manufacturing, use, and end-of-life stages in the ICT sector. The focus is on enabling greener decision-making through systemic, data-driven sustainability practices.

The module is designed around two key units, each contributing progressively to the learner's ability to design next-gen sustainable systems:

- Unit 2.1: Life Cycle Assessment (LCA) in ICT
- Unit 1.2: Circular Economy Strategies in Green Networks

Unit 2.1, Life Cycle Assessment (LCA) in ICT, provides learners with a structured, comprehensive understanding of how environmental impacts arise across every stage of digital technologies, from raw material extraction to manufacturing, use, and end-of-life. Through its six sections, the unit moves from foundational concepts such as life cycle thinking to the practical steps of conducting an LCA, the data and tools required, real ICT case studies, and finally the limitations and future evolution of LCA for fast-moving sectors like 5G and beyond. The unit's purpose is to equip learners with both the conceptual clarity and analytical confidence needed to interpret, conduct, and apply LCA in the context of modern communication networks.

By the end of the unit, students understand not only how to quantify environmental hotspots in ICT devices and infrastructure, but also how these insights inform eco-design, procurement, policy development, and circular-economy strategies. Positioned within the broader course *Green Skills for Beyond 5G Technologies*, this unit ensures that future engineers, policymakers, and sustainability professionals can make evidence-based decisions that reduce carbon intensity, avoid burden shifting, and support greener network evolution.

Unit 2.2 explores how circular economy principles can be applied to ICT and Beyond-5G networks to reduce environmental impact and keep products, components, and materials in circulation for longer. It introduces the shift from linear to circular thinking and covers practical strategies such as designing modular, long-life equipment, enabling reuse and refurbishment, improving recycling and material recovery, and building effective reverse-logistics systems. The unit also highlights the key metrics used to assess circularity in telecom infrastructures.

The purpose of this unit is to help learners understand how circular practices can make digital networks more sustainable, resilient, and cost-efficient. By the end, learners should be able to evaluate circular strategies and recognise how design choices, end-of-life management, and measurement tools contribute to greener and more future-ready telecom systems.

The workload of Module 2 was monitored using the methodology applied to the implemented units, distinguishing between lecture hours, exercise hours, and self-study hours. For Unit 2.1, the initially planned workload was 8 hours. The final implemented workload comprised

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approximately 2 h 53 min of lecture time, 2 h 00 min of exercise time, and approximately 3 h 30 min of self-study time. For Unit 2.2, the initially planned workload was 7 hours, including approximately 2 h 33 min of lecture time, 1 h 45 min of exercise time, and 3 h 00 min of self-study time. These calculations were based on the effective duration of lesson videos, self-evaluation quizzes, case-study lecture materials, assignment exercises, transcript-supported slides, and references.

Module 3 (Energy Efficiency and Carbon Reduction Strategies)

Module 3 focuses on reducing the energy and carbon footprint of 5G and ICT networks. It covers energy consumption patterns, optimization techniques, and low-carbon technologies. Emphasis is placed on monitoring, reporting, and improving sustainability performance. Learners explore practical strategies for greener telecom operations and infrastructure.

The module is designed around two key units, each contributing progressively to the learner's ability to design next-gen sustainable systems:

- Unit 3.1: Energy Consumption in 5G and Optimization Techniques
- Unit 3.2: Carbon Footprint Monitoring and Reduction in Telecom

Unit 3.1: Energy Consumption in 5G and Optimisation Techniques introduces how and why 5G networks consume energy and outlines the key strategies used to reduce this footprint. As 5G brings higher data rates, denser deployments, and more complex processing, understanding where energy is spent, especially in the RAN, is essential for improving both sustainability and operational efficiency.

The unit provides an overview of the main optimisation approaches, from efficient hardware and cooling design to dynamic energy-management features, software-based virtualisation, and renewable-energy integration. It also covers the benchmarking methods used to measure real improvements. By the end, learners gain a concise but practical foundation for designing and managing greener 5G and Beyond-5G networks.

Unit 3.2 introduces how the telecom sector measures, monitors, and reduces its carbon footprint across networks, infrastructure, and supply chains. Across its six sections, it outlines where emissions come from, the standards and tools used to account for them, and the practical approaches, from low-carbon deployment to operational optimisation and offsetting, that support credible emissions reduction.

The purpose of this unit is to help learners understand both *how* carbon is assessed and *why* reduction is essential for 5G and future networks. By the end, learners are equipped with the knowledge needed to support climate-aligned operations, informed sustainability decisions, and meaningful progress toward Net Zero goals within the ICT sector.

The workload of Module 3 was monitored using the methodology applied to the implemented units, distinguishing between lecture hours, exercise hours, and self-study hours. For Unit 3.1, the initially planned workload was 8 hours. The final implemented workload comprised approximately 2 h 49 min of lecture time, 2 h 00 min of exercise time, and approximately 3 h 30 min of self-study time. For Unit 3.2, the initially planned workload was 7 hours, including approximately 2 h 27 min of lecture time, 1 h 45 min of exercise time, and 3 h 00 min of self-study time. These calculations were based on the effective duration of lesson videos, self-evaluation quizzes, case-study lecture materials, assignment exercises, transcript-supported slides, and references.

In terms of Pedagogical Strategy, each unit of Modules 2 and 3 is built using modular chapters, and each chapter is split into sections that act as atomic learning blocks, typically combining text, visuals, and short multimedia or interactive content. These sections focus on specific design patterns, tools, or concepts, fostering both conceptual understanding and applied capability.

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Module 4 (Regulatory, Ethical, and Business Perspectives on Green 5G)

Within the overall course framework, **Module 4** focuses on the regulatory, ethical, and business dimensions of green 5G deployment. It contributes to learning outcomes related to understanding sustainability-related regulations and standards for telecom systems, analysing ethical considerations in sustainable technology deployment, evaluating business strategies aligned with environmental goals, and aligning green initiatives with policy, regulatory, and stakeholder expectations.

Module 4 was also implemented through two units:

- Unit 4.1: Regulations, Standards, and Ethics in Green ICT
- Unit 4.2: Business Models and Policy Advocacy for Sustainable 5G

Unit 4.1 introduced the regulatory and ethical landscape underpinning sustainable 5G and Beyond 5G systems. It included lesson-level sections on introduction, regulatory frameworks, standards and metrics, and ethics and governance. The unit was complemented by the case study **"Life Cycle Assessment of 5G Infrastructure,"** which combined two video parts, transcript-supported slide materials, and an assignment exercise.

Unit 4.2 addressed the business and governance dimensions of sustainability in telecom systems. It included sections on green business models in telecom, business model canvas for green 5G innovation, financing and incentives for green telecom projects, ICT policy advocacy and green governance, designing impactful policy briefs, and greenwashing, risk, and reputation management. The unit concluded with a case-study-based exercise centred on **modelling a business case**, supported by a video presentation, transcript-style exercise slides, and an assignment exercise.

As in Module 1, the lessons in Module 4 followed a standardised digital format built around **video presentations**, **presentation slides with transcript-style speaker notes**, and **self-evaluation quizzes**. This format was intended to support independent progression through the content and to ensure a coherent structure across lessons and units. It also supported dimensions later captured in the pilot questionnaire, including **clarity and consistency**, **alignment between materials and learning objectives**, **engagement**, and the **usefulness of assessment and applied activities**.

The workload of Module 4 was likewise monitored using the same calculation methodology. For **Unit 4.1**, the initially planned workload was **8 hours**, while the implemented workload reached **8 h 35 min**. This included approximately **2 h 47 min of lecture time**, **2 h 40 min of exercise time**, and **3 h 08 min of self-study time**. For **Unit 4.2**, the initially planned workload was **7 hours**, whereas the implemented workload reached **9 h 30 min**, with around **3 h 42 min of lecture time**, **3 h 00 min of exercise time**, and **2 h 51 min of self-study time**. In both units, the calculations took into account lesson videos, self-evaluation quizzes, case-study lecture materials, assignment exercises, transcript-supported slides, and recommended references. The monitoring, therefore, showed that **Unit 4.1** remained relatively close to the planned workload, while **Unit 4.2** exceeded the initial estimate by a greater margin, indicating the need for further balancing within the refined course structure.

From a pedagogical perspective, Module 4 combined **regulatory and ethical analysis**, **business-oriented sustainability content**, **formative self-assessment**, and **applied case-study work**. The practical tasks were intended to enable learners to connect policy, regulation, ethics, and business planning with sustainability-oriented decision-making in realistic telecom scenarios. This implementation logic is consistent with the broader curriculum approach, in which applied activities are used not only to reinforce understanding but also to encourage reflection, transfer, and contextualised problem-solving.

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The Moodle course also included the **pilot evaluation survey**, through which learners were invited to provide structured feedback on course organization, clarity, relevance, quality of resources, pedagogical approach, digital delivery, and, where applicable, the value of problem-based and case-based learning activities. In this way, the digital environment served not only as the medium for course delivery but also as the operational setting for collecting pilot evidence later used in the evaluation and refinement process described in this deliverable.

Overall, the implemented modules supported a sustainability-oriented learning pathway that connected **green design principles**, **eco-design practices**, and **regulatory, ethical, and business perspectives** relevant to 5G systems. The pilot implementation was especially useful for assessing whether these different dimensions could be presented coherently within the same digital course environment and whether case-study activities could help learners relate sustainability concepts to realistic design and decision-making situations. As such, the implemented parts of the course contributed to validating the curriculum not only in terms of content delivery but also in terms of interdisciplinary coherence and practical relevance.

3.7.2. Feedback and Observations

The pilot feedback collected for the course **Green Skills for Beyond 5G Technologies** indicates an overall positive evaluation of the course, while also revealing several recurring issues related to workload, assessment density, learner engagement, and the clarity of applied tasks. A total of **22 valid responses** were reviewed, corresponding to **11 Master students, 7 PhD students, and 4 Bachelor students**. Overall, the feedback confirms that the course is perceived as relevant, coherent, and academically valuable, but also shows that several aspects of the implemented learning experience require refinement in order to better support usability, practical application, and workload balance. This interpretation is consistent with the role of the course within the wider 5G-DiGITs curriculum, which is intended to connect sustainability, circularity, policy, and innovation to advanced 5G systems.

A review of the quantitative results shows that the strongest dimensions are **clarity, consistency,** and **alignment between modules, activities, and learning outcomes**, both with an average score of **4.18/5**. These are followed by **relevance to current trends** and **structure and organization**, both rated 4.09/5, and by knowledge and skills improvement, rated **4.05/5**. The course also performs well in relation to **theory-practice connection** (**3.95/5**), **case studies' usefulness** (**3.95/5**), **authenticity and alignment of the PBL/problem scenarios** (**3.95/5**), and **theoretical foundation** (**3.91/5**). These results indicate that learners generally recognize the course as a coherent, academically sound offering with strong relevance to current sustainability challenges in the telecom and ICT sectors. This is fully in line with the curriculum logic defined in D2.2, where the course was conceived as a structured 2 ECTS learning offer combining green ICT principles, circular economy, energy efficiency, and regulatory/business perspectives.

At the same time, the dataset highlights several weaker areas. The lowest-rated dimension is **fit to learner profile**, at **3.36/5**, followed by **assessment usefulness** (**3.55/5**), **teaching methodology** (**3.59/5**), and both **engagement and satisfaction** and **digital tools integration**, each at **3.64/5**. **Practical application** and **self-directed learning** also remain below the strongest dimensions, both at **3.82/5**. This pattern suggests that the course is not being rejected for lack of relevance or academic quality; rather, the tension lies in how the content is delivered, how activities are structured, and how well the implemented learning pathway matches the expectations and interests of all learner profiles. In this sense, the relatively lower score for fit to profile appears to reflect the specialized nature of the course as much as any intrinsic weakness in the subject matter itself.

This interpretation is reinforced by the qualitative comments. Several learners explicitly value the course for its **comprehensive coverage of green ICT pillars**, including life-cycle assessment, circular economy, energy efficiency, carbon reduction, and regulatory/business dimensions.

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Other comments underline the **clear relationship between slides, videos, quizzes, and assignments**, and note that the course structure makes progression through the material understandable. The qualitative evidence also confirms that the course is perceived as particularly relevant for learners with a stronger interest in sustainability and green telecom themes. These strengths are important because they show that the course concept itself is solid and that its interdisciplinary composition is understandable and meaningful to participants. This positive reception is also consistent with the design principles described in D2.2 and with the case-study ecosystem developed in D2.3, which was intended to help connect theory, metrics, policy, and decision-making in realistic contexts.

The main weaknesses identified through the comments are also highly consistent. Learners repeatedly mention that the course can feel **too dense** for a 2 ECTS offer, with **heavy case studies**, **too many quizzes**, and a generally high workload compared with other courses. A second recurring issue is the **theoretical heaviness** of some units, particularly when long stretches of explanatory material are combined with limited interactivity. A third recurring issue concerns **AI-generated narration**, which is perceived as monotonous and less effective for sustaining attention. A fourth important issue is that **assignment expectations are not always sufficiently clear**, especially where instructions are primarily embedded in videos and slides rather than presented in a concise written brief. Finally, some learners note the uneven presence of **additional supporting materials**, such as readings, links, key takeaways, or worked examples, and one of the clearest comments points to **conceptual overlap**, especially across topics related to circular economy, energy efficiency, and emissions. Taken together, these findings indicate that the key refinement needs concern **instructional design and scaffolding**, not the relevance of the course topic itself.

A further point of interpretation arises when the learner feedback is read alongside the implementation evidence already documented in Section 3.7.1. The implementation monitoring shows that **both units of Module 1 exceeded their initially planned workload**, and that **Unit 4.2 also exceeded its initial estimate**, while Unit 4.1 remained closer to plan. This does not by itself prove that these are the only sources of workload pressure perceived by students, but it does provide concrete implementation evidence that the learner comments on density and effort are grounded in the actual structure of the course as delivered. Similarly, the course design in D2.2 envisaged a balanced 60-hour learning pathway with clearer workload assumptions for lectures, practical exercises, quizzes, and final assessment, whereas the pilot feedback suggests that the implemented assessment experience may have felt more fragmented and more demanding than intended.

Overall, the pilot feedback leads to three main conclusions. First, the course is **relevant, coherent, and intellectually strong**, especially for learners interested in sustainability and green telecom innovation. Second, the main weaknesses concern **engagement, workload balance, assessment density, and applied scaffolding**, rather than conceptual legitimacy or lack of topical relevance. Third, the refinement strategy should therefore preserve the current course identity while improving the **usability and practical accessibility** of the implemented learning pathway.

3.7.3. Refinements and Adjustments

On the basis of the pilot evidence, the refinement strategy for **Green Skills for Beyond 5G Technologies** aims to **preserve the academic strength and relevance of the course while improving its usability, workload balance, and applied scaffolding**. The available data do not suggest the need for a structural redesign of the course concept. Rather, they indicate that the current four-module architecture is pedagogically valid, but that the implemented delivery format should be adjusted so that learners can engage with the material more efficiently and with stronger practical guidance. This direction is fully consistent with the original course

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rationale in D2.2, where the course was conceived as an interdisciplinary green-skills offer combining theoretical grounding, applied work, and sustainability-oriented decision-making in a 2 ECTS format.

A first refinement line concerns the **course's assessment architecture**. The feedback clearly shows that the current quiz experience is perceived by some learners as too frequent, sometimes too simple, and not always proportionate to the overall course workload. In the refined version, the assessment structure should therefore be rationalized by consolidating self-evaluation activities at a more manageable level, preferably at the **unit level** rather than repeating section-level testing where appropriate. This will reduce perceived fragmentation, improve the usefulness of formative assessment, and bring the implemented experience closer to the intended workload logic already described in D2.2, where assessment was meant to remain transparent and proportionate within the 60-hour course frame. At the same time, the distinction between low-stakes formative checks and more substantial case-based or assignment-based tasks should be made clearer to learners.

A second refinement line concerns **assignment scaffolding and task clarity**. One of the most actionable findings in the qualitative feedback is that the expected outputs of some case assignments are not always sufficiently clear when instructions are delivered mainly through video and slides. In the refined version, each assignment should therefore be accompanied by a brief, ideally in a concise PDF or equivalent downloadable format, clearly stating the task objective, the expected steps, the required deliverables, the evaluation criteria, and the indicative time commitment. This change will improve learner confidence, reduce avoidable uncertainty, and strengthen the usability of the case-study units without changing their substantive content. It will also align more closely with the transparency and feedback principles already embedded in the broader curriculum framework.

A third refinement line concerns **audiovisual delivery and presentation quality**. The pilot comments make it clear that AI-generated narration negatively affects attention and sustained engagement, even where the underlying content is valued. The refined version should therefore revise narration scripts, improve pronunciation and pacing, and, where feasible, replace or substantially improve the current AI-generated voice delivery. In parallel, materials should be revised to reduce text density and increase visual hierarchy, particularly in units where sustainability concepts, metrics, or policy content are presented in extended explanatory form. Shorter key-takeaway elements, clearer diagrams, and more concise visual framing will likely improve both engagement and retention without requiring changes to the course's conceptual scope. These refinements will also be consistent with the broader cross-course lesson already emerging in D2.6, namely that AI-only narration and overly dense presentation formats systematically reduce learner satisfaction.

A fourth refinement line concerns **guided practical application**. Although the course already performs positively in relation to case studies, theory-practice connection, and authenticity, the comments show that learners still want more concrete worked examples and clearer practical anchors. In the refined version, additional scaffolding should therefore be introduced through short guided examples, especially for topics such as sustainability metrics, LCA interpretation, energy and emissions indicators, eco-design trade-offs, and business or regulatory analysis. These examples should not replace the case-study activities, but rather better prepare learners for them by demonstrating how concepts are operationalized step by step. This will strengthen the weaker dimensions of practical application and teaching methodology while preserving the course’s analytical depth. It will also align well with the case-study logic already established in D2.3 for the Green Skills course, where sustainability concepts are meant to be translated into realistic design, evaluation, and policy-oriented tasks.

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A fifth refinement line concerns **navigation, orientation, and supporting resources**. One of the clearer learner suggestions is the need for a stronger introductory roadmap on the first page of the course, explaining the course structure, the progression, and the relationships among videos, quizzes, readings, and assignments. This should be implemented through a more explicit landing-page overview, clearer material grouping, and short unit-level summaries. In addition, the distribution of complementary resources should be made more consistent by ensuring that units systematically include, where appropriate, further readings, useful links, short synthesis notes, or key takeaways. This is especially important in a specialized course such as this one, where the lower fit-to-profile score suggests that some learners need stronger orientation and scaffolding to remain engaged with technically or conceptually dense material.

A sixth refinement line concerns **content streamlining and workload balancing**. The qualitative feedback points to conceptual overlap, especially across the themes of circular economy, energy efficiency, and emissions, while the implementation record already shows that some units exceeded their initial workload assumptions. The refined version should therefore reduce repetition across related modules, especially in the middle of the course where sustainability frameworks, metrics, and optimization concepts may converge. At the same time, the workload should be rebalanced in units already shown to be heavier than planned, particularly in **Module 1** and **Unit 4.2**, with greater transparency on expected effort and a clearer balance between reading, audiovisual material, quizzes, and applied work. This refinement should be understood as **internal optimization**, not as a reduction of the course's specialist character. The aim is to maintain the intellectual richness of the course while making the learning path more proportionate to the intended 2 ECTS format.

Taken together, these preliminary refinements support a clear course-level conclusion: **Green Skills for Beyond 5G Technologies should remain a specialized, sustainability-oriented course, but its implementation should be made lighter, clearer, and more practice-ready**. The evidence does not justify a redesign of the course identity; it justifies a more disciplined implementation of assessment, navigation, scaffolding, and workload management.

Scope	Refinement area	Adjustment
Whole course	Assessment rationalization	Consolidate quizzes at a more manageable level, reduce redundancy, and clarify the distinction between formative checks and larger assignment-based tasks
Whole course	Audiovisual delivery	Revise narration scripts, improve pronunciation and pacing, and improve or replace AI-based audio where feasible
Whole course	Navigation and orientation	Add a clearer landing-page roadmap, improve grouping of materials, and provide short unit-level summaries
Whole course	Supporting materials	Ensure more consistent use of readings, links, key takeaways, and concise supporting resources across units
Whole course	Workload transparency	Make expected effort more explicit and improve the balance between videos, readings, quizzes, and applied tasks

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Modules 2-3	Content streamlining	Reduce conceptual overlap across circular economy, energy efficiency, and emissions-related content
Modules 2-3	Guided examples	Add clearer metric definitions and worked examples to support understanding of sustainability indicators and applied analysis
Case-study units	Assignment briefs	Provide a concise written brief for each assignment, including objectives, steps, evaluation criteria, and deliverables
Case-study units	Practical scaffolding	Add templates, checklists, and short guided examples to support learners before they complete the case-study tasks independently
Workload-critical units	Internal balancing	Rebalance the heaviest units, especially where implementation monitoring already showed workload overruns, without weakening the specialist character of the course

Table 8. Summary of refinement actions

3.8. Entrepreneurial Skills for Beyond 5G Technologies

3.8.1. Course Implementation

The course **Entrepreneurial Skills for Beyond 5G Technologies** was developed within the 5G-DiGITs curriculum to strengthen the entrepreneurial capabilities required for innovation in the Beyond 5G (B5G) technology ecosystem. The course aims to provide comprehensive knowledge, skills, and abilities (KSA) in entrepreneurship tailored to professionals and learners working in the 5G domain. Aligned with the Erasmus+ framework and the KSA methodology, the course integrates innovation practices, leadership development, business fundamentals, and resilience-building competencies to support the creation and growth of technology-driven ventures in the rapidly evolving telecommunications landscape.

The course follows a structured entrepreneurial learning journey, beginning with innovation and creativity techniques that support problem identification and opportunity discovery within the 5G market. These foundations are then expanded through leadership and problem-solving approaches, enabling learners to identify market gaps and lead entrepreneurial initiatives. The course further introduces essential business concepts required to transform validated ideas into viable ventures, while also emphasizing resilience, adaptability, and risk management as key competencies for long-term entrepreneurial success in dynamic and technology-driven markets.

The course is structured into four thematic modules:

- **Module 1:** Innovation & Creativity
- **Module 2:** Problem Solving & Leadership Opportunities in the 5G Market
- **Module 3:** Business Fundamentals for 5G Ventures
- **Module 4:** Building Resilience in Entrepreneurship

Module 1: Innovation & Creativity

Module 1 introduces the foundational innovation mindset required for entrepreneurship in the 5G ecosystem and it is spilt into two Units:

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- Unit 1.1: **Design Thinking for 5G Innovation**
- Unit 1.2: **Open Innovation and 5G Ecosystem Collaboration**

Through the first *unit* ***(Unit 1.1 Design Thinking for 5G Innovation)*** , learners explore Design Thinking and human-centred innovation methodologies, learning how to translate advanced 5G technological capabilities—such as ultra-low latency, edge computing, and massive IoT—into solutions that address real user needs. The unit presents structured innovation processes including empathy research, problem definition, ideation, rapid prototyping, and iterative testing. By combining approaches from design thinking, Lean Startup methodology, and behavioural insights, learners develop the ability to identify opportunities, generate creative ideas, and validate potential 5G applications across sectors such as healthcare, manufacturing, and smart cities.

The *second unit* ***(Unit 1.2 Open Innovation and 5G Ecosystem Collaboration)*** expands this perspective by introducing open innovation and ecosystem collaboration as essential drivers of 5G development. Learners examine how innovation in the telecommunications sector increasingly relies on cooperation among multiple stakeholders, including telecom operators, technology vendors, cloud providers, startups, research institutions, and regulators. Through stakeholder mapping, partnership strategies, and real-world case studies, the module highlights how collaborative innovation models enable value creation and new business opportunities within complex 5G ecosystems. Together, the two units equip learners with the creative, analytical, and collaborative competencies necessary to develop innovative solutions and entrepreneurial initiatives in the evolving 5G landscape.

This module combines theoretical instruction with practical engagement to support a comprehensive learning experience. Alongside lectures and conceptual materials, learners are encouraged to apply key concepts through a range of practical tools (Empathy Map Canvas, Design Thinking Templates, Human-Centered Design Approaches for 5G technologies, Storytelling, Pitch Decks), guided exercises, and self-assessment quizzes. In addition, learners are provided with curated readings, guides, and supplementary resources for independent study, allowing them to deepen their understanding and further develop practical entrepreneurial skills.

Module 2 Problem Solving & Leadership Opportunities in the 5G Market

Module 2 was implemented as a two-unit module combining structured problem-solving methodologies with leadership and team-management skills tailored to 5G and Beyond 5G innovation contexts.

Unit 2.1, “Structured Problem Solving for 5G Market Opportunities”, focused on guiding learners through a step-by-step process for diagnosing market needs, analysing the 5G business and technical environment, and prioritising innovation opportunities. It introduced and applied frameworks such as SWOT and PESTEL analysis, Blue Ocean Strategy, and iterative cycles of market research, prototyping, and solution refinement, using case studies and practical assignments related to emerging 5G use cases and vertical applications. The implementation emphasised a repeatable, evidence-based problem-solving approach, enabling participants to translate complex 5G capabilities into viable opportunity spaces and initial solution concepts.

Unit 2.2, “Leadership and Team Management in Technical Ventures”, explored leadership styles and team-dynamics principles that are critical for high-performing technical teams operating in rapidly evolving 5G environments. Learners examined and compared leadership approaches (e.g. transformational, servant, democratic and more structured styles) and reflected on how these influence motivation, collaboration, and innovation within multidisciplinary 5G projects. Through examples, exercises and self-reflection activities, the unit supported students in developing practical skills for coordinating teams, managing conflict,

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empowering team members, and sustaining agile, innovation-oriented work practices in 5G ventures and projects.

Module 3: Business Fundamentals for 5G Ventures

Module 3 focuses on the core business and commercial competencies required to transform 5G innovations into viable and scalable ventures. It equips learners with the knowledge and tools to design sustainable business models, manage financial complexity, and successfully position and launch products in competitive, enterprise-driven markets. This module is broken down into two Units which are briefly described below:

Unit 3.1 – Business Fundamentals for 5G Ventures

This unit provides a comprehensive and practical foundation for building and sustaining 5G ventures in a complex, capital-intensive environment. It introduces key business modelling frameworks—such as the Business Model Canvas, Customer Development, and Lean Startup—adapted to the specific requirements of deep-tech and telecommunications innovation. Learners explore how business models differ across 5G segments (eMBB, URLLC, mMTC) and industry verticals, while also understanding the importance of partnerships, regulatory considerations, and ecosystem positioning. Through real-world case studies, the unit demonstrates how successful ventures design value propositions and operational models that respond to long sales cycles, high infrastructure costs, and evolving market demands. In parallel, the unit places strong emphasis on financial strategy and investment readiness. Learners develop skills in financial modelling, cash flow management, unit economics, and capital planning, while also gaining insight into funding mechanisms, valuation approaches, and investor expectations in deep-tech markets. The unit further introduces market analysis tools (TAM, SAM, SOM) and pitch development techniques, enabling learners to align business design with financial sustainability and growth. Overall, it prepares participants to build resilient, adaptable 5G ventures that integrate business, financial, and technological considerations.

Unit 3.2 – Marketing and Go-to-Market Strategy

This unit equips learners with the strategic and practical tools required to effectively market and commercialize 5G solutions in complex, multi-stakeholder environments. It adapts established marketing frameworks—such as segmentation, targeting, and positioning (STP), the Technology Adoption Lifecycle, and the extended marketing mix—to the realities of 5G markets, where solutions are often infrastructure-based, highly technical, and primarily B2B-oriented. Learners explore how to translate 5G capabilities into clear business value propositions tailored to specific industry verticals, including manufacturing, healthcare, and smart cities. The unit further focuses on designing and executing effective go-to-market strategies, emphasizing ecosystem partnerships, channel development, and innovative pricing models aligned with customer value. It also covers implementation through digital marketing, content strategy, and account-based marketing approaches, alongside performance measurement and continuous optimization. By the end of the unit, learners are able to plan, launch, and scale 5G products and services, ensuring successful market adoption and long-term competitive positioning.

This module integrates solid theoretical foundations with practical, hands-on engagement to deliver a comprehensive and applied learning experience. It includes video lectures—accompanied by transcripts to ensure accessibility—alongside structured templates and real-world examples that guide learners in applying key frameworks, strategic approaches, and business modelling tools. The learning experience is further enriched through self-evaluation quizzes, practical exercises, and curated readings, enabling participants to actively test and deepen their understanding. Together, these elements reinforce the module's scientific rigor while ensuring its relevance, usability, and alignment with real-world entrepreneurial practice.

Module 4: Building Resilience in Entrepreneurship

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Module 4 was implemented as a two-unit module designed to strengthen learners' ability to anticipate risks, safeguard 5G ventures, and maintain long-term viability in complex technological and market environments.

Unit 4.1, "Risk Assessment and Contingency Planning", introduced core concepts and processes for systematically identifying, evaluating, and mitigating technical, business, regulatory, and societal risks in 5G-related projects and enterprises. Learners worked with structured risk-mapping and impact–likelihood assessment approaches, and were guided through the design of contingency plans and response strategies aimed at ensuring business continuity and organisational resilience in the face of disruptions affecting 5G networks and services. Through explanatory materials, case examples and applied exercises, the unit fostered a proactive mindset towards risk, helping participants move from ad hoc reactions to planned, evidence-informed resilience practices.

Unit 4.2, "Networking and Resource Management", focused on how strategic relationship-building and effective use of resources contribute to resilience and growth in the advanced 5G landscape. The implementation highlighted the role of business networking in accessing new markets, specialised expertise, capital and other critical resources, and linked this to practical strategies for optimising internal resource allocation and developing mutually beneficial partnerships. Learners engaged with examples, tools and reflective activities that illustrated how well-managed networks and resources can enhance innovation capacity, problem-solving, and operational robustness for 5G-focused ventures and projects.

The course adopted a modular pedagogical structure, with each unit combining short, focused video lectures, slide-based explanations, and targeted readings to introduce and consolidate key concepts in entrepreneurial thinking for B5G technologies. Learners progressed through clearly sequenced online units that integrated self-evaluation quizzes, reflective questions, and simple applied tasks, supporting gradual transfer from foundational ideas to practical application. Where relevant, the course also drew on brief case vignettes and example scenarios from the digital and green transition domains, enabling participants to connect entrepreneurial skills with real-world opportunities in advanced 5G contexts. The Moodle course space brought these elements together in a unified learning pathway, ensuring that resources, activities, and assessments were accessible in a coherent and navigable structure.

Overall, the implementation of this course provides a structured, online learning experience that linked core entrepreneurial competences with the specific opportunities and challenges of the B5G landscape. The combination of modular units, varied digital resources, and applied activities enables learners to relate conceptual tools (such as opportunity recognition, value proposition design, and basic business modelling) to concrete technological and market contexts. As a result, the course contributes to the broader curriculum objective of equipping learners not only with technical knowledge, but also with the entrepreneurial mindset needed to translate 5G and Beyond 5G innovations into viable solutions and initiatives.

3.8.2. Feedback and Observations

This report is based on a total of 24 responses collected through a course evaluation survey. The instrument combines quantitative ratings, using scale-based questions, with qualitative feedback obtained through open-ended responses.

From a quantitative perspective, the overall evaluation of the course is very positive and consistent with the trends observed in other courses analyzed within the program. There is a clear predominance of high scores, with most responses concentrated in the upper range of the scale. Additionally, the level of dispersion is low, indicating a strong degree of consistency among participants. Only a limited number of negative ratings are recorded.

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Among the most highly valued aspects, participants highlight the usefulness of the content for both personal and professional development, as well as the clarity with which key concepts are presented. The motivational approach of the course is also positively recognized, contributing to student engagement, alongside the overall organization, which is perceived as coherent and well structured.

Despite these strengths, some areas for improvement are identified. In particular, participants point to the need for greater depth in specific entrepreneurship-related tools, especially those linked to funding methods. There is also a recurring demand for more practical application of the concepts presented, as well as concerns that certain parts of the content are too general in nature.

In summary, the course is very well regarded and demonstrates a high level of consistency in student evaluations. Its main strengths lie in the clarity, organization, and practical relevance of its content, as well as in its motivational approach. However, enhancing the level of depth in specific topics and increasing the practical orientation of the course will further strengthen its overall effectiveness.

A review of the quantitative results shows a clear predominance of high scores across all evaluated dimensions, with low dispersion among responses, indicating strong consistency in learner perceptions. The strongest dimensions relate to the usefulness of the content for personal and professional development, the clarity of concept presentation, the motivational approach of the course, and its general organization. These results suggest that learners not only understand the material but also perceive it as directly valuable and applicable to their own development pathways. In particular, the motivational dimension stands out, with many learners highlighting that the course successfully fosters an entrepreneurial mindset rather than focusing solely on technical or theoretical knowledge. This aligns well with the course design intention, which emphasizes mindset development, opportunity recognition, and innovation awareness in the context of Beyond 5G ecosystems.

The course also performs positively in terms of accessibility and structure. Learners consistently note that the content is clear, easy to follow, and well-organized, which is further reinforced by the multiformat delivery approach combining videos, readings, and quizzes. The integration of real-world use cases and recent examples is also recognized as a strength, contributing to the perceived relevance of the course and helping to ground abstract entrepreneurial concepts in realistic scenarios. Additionally, the use of quizzes is generally appreciated, with respondents indicating that they are well-aligned with the course content and effective in reinforcing learning. The problem-first teaching approach adopted in some lectures is also highlighted as an effective engagement strategy, suggesting that learners respond positively to methods that introduce challenges before presenting solutions.

At the same time, the dataset highlights several weaker areas that follow a consistent pattern across both quantitative ratings and qualitative feedback. The most recurrent issue concerns the limited depth of practical and technical aspects of entrepreneurship. Learners frequently point out that while the course provides a strong conceptual introduction, it does not sufficiently cover the concrete steps involved in creating and implementing a business, such as securing funding, or executing extensive entrepreneurial strategies but more preliminary. This is reflected in lower ratings related to practical application and depth of content, as well as in comments describing some modules as more general.

A second important issue relates to the balance between different learner profiles. Feedback reveals tension between participants with strong technical backgrounds in 5G and those approaching the course from a business or innovation perspective. While some learners perceive parts of the course as too basic, others find certain technical references insufficiently explained. This divergence suggests that the course, while accessible, does not always fully align

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with the expectations of all learner groups. In this sense, the challenge is not a lack of quality, but rather the need for clearer signalling of the intended audience and level of complexity.

A third recurring theme concerns engagement and delivery format. Although the course is generally described as motivating and inspiring, some learners report difficulties in maintaining attention, particularly in relation to the use of AI-generated narration. The voiceover is frequently perceived as monotonous or lacking expressiveness, which negatively affects the overall learning experience. While this issue does not undermine the perceived value of the content itself, it represents one of the clearest and least contested areas for improvement.

Further qualitative feedback highlights additional areas for refinement. Learners note the scarcity of detailed real-world case studies and success stories, as well as the limited availability of short hands-on exercises or interactive activities that would allow them to apply the concepts in practice in realtime. Suggestions for improvement icould focus on funding intiatives , around Europe. and heavier implementation-oriented tasks. In addition, some respondents point to structural aspects of the course, noting that certain sections are too long and would benefit from being divided into smaller, more clearly defined units to improve navigation and usability. A smaller number of comments also identify overlaps with related courses within the program, suggesting the need for clearer differentiation and articulation of the course's unique value proposition, although overlaps exist since courses can be taken as a standalone course.

Taken together, these findings indicate that the course is not being challenged in terms of its relevance, clarity, or pedagogical coherence. On the contrary, its strengths are consistently recognized across all types of feedback. The main areas for improvement instead concern the depth of practical content, the enhancement of engagement through delivery and interactivity, and the alignment of the course structure and scope with the expectations of a diverse learner audience.

Overall, the pilot feedback leads to three main conclusions. First, the course is highly effective as an introductory and motivational learning experience, successfully fostering an entrepreneurial mindset in the context of Beyond 5G technologies. Second, its main limitations relate to insufficient audience profiling, as well as a lack of practical and technical depth, in addition to certain delivery and engagement issues. Third, the refinement strategy should therefore aim to preserve the current strengths of the course while enhancing its practical applicability, improving delivery quality, and clarifying its positioning within the broader curriculum. In this regard, participants consistently recommend maintaining the course as a solid introductory foundation while developing a more advanced level that incorporates elements such as business model development (e.g., Canvas), detailed real-world case studies, simulations or hands-on practical exercises, and a stronger focus on financial and execution aspects.

3.8.3. Refinements and Adjustments

Based on the feedback analysed in the previous section, the course demonstrates a strong foundation: its content is relevant, well-structured, and pedagogically coherent. Some areas for improvement relate primarily to the quality of delivery (particularly human narration), clearer definition of the target audience, and the potential enhancement of practical and interactive elements—despite some mixed responses in this area. Addressing these aspects significantly improves learner engagement and satisfaction, without necessitating a fundamental redesign of the course

The course attracted a diverse mix of learners, including PhD candidates, Master's students, and some undergraduate students. The majority of respondents confirmed that the course effectively improved their knowledge and skills with several noting it provided valuable coverage of innovation and entrepreneurship in the 5G context. The integration of real-world use cases and recent examples was specifically praised as a strength — learners appreciated that the

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course didn't just teach theory but grounded concepts in current, realistic scenarios. The problem-first teaching approach used in some lectures (introducing a challenge before explaining solutions) was highlighted as an effective engagement strategy. Quizzes were also recognized as well-aligned with course content and useful for reinforcing learning. The multiformat approach — combining videos, reading materials, and quizzes — was well received as supporting diverse learning styles.

Areas of improvement

1. Delivery: Move toward a human presence in lectures. The feedback regarding the delivery format, particularly the use of AI-generated voiceover, has been carefully considered. While a complete transition to human narration will require substantial resources and is not currently feasible, a set of targeted improvements have been implemented to enhance the overall learning experience. These include optimizing voice modulation, pacing, and expressiveness through updated AI voice configurations, as well as segmenting lecture content into shorter and more engaging units. In addition, selected elements such as brief introductions, transitions, or key takeaways have been incorporated to introduce a stronger sense of presence. Finally, a systematic review of audio quality will be conducted to address any reported technical artifacts. These measures aim to improve learner engagement while maintaining the scalability and consistency of the current course delivery approach. As this seemed a consistent comment for the other courses , the respondents commented to the AI-generated voiceover used in lectures as some found it monotone, and sometimes disengaging. While some respondents were neutral on this, none praised it — making this the clearest, least contradicted area for improvement. The recommendation is to either replace AI narration with real human narration or significantly improve voice quality, pacing, and expressiveness. Additionally, audio quality should be reviewed across all lectures, as technical artifacts have been reported even for other courses too.

2. Audience targeting and profile fit: Feedback reveals a tension between learners with deep technical 5G backgrounds and those approaching from a business or innovation angle. Some found certain sections too basic, while others found technical references unclear. The recommendation is to more explicitly define the intended learner profile at the outset ensuring prospective participants understand the course scope. Clearly signal the level of difficulty and expected prior knowledge for each module could also improve this area.

3. Engagement and practical components: This area seemed the most contradictory in replies, where in open comments some learners found the course engaging through its case studies, while others found it hard to stay focused — the positive signal is clear: the case studies and practical examples are working. The recommendation is to lean further into this strength by adding more self-assessment exercises, interactive elements, and scenario-based tasks that put learners in the driver's seat. Some assignments could possibly be redesigned to focus on creating scalable, forward-looking solutions rather than solving predefined problems.

4. Course structure: granularity and navigation Some learners noted that the course is organized into a small number of very long sections, making it harder to navigate and locate specific content. The recommendation is to divide existing long sections into smaller, clearly titled units with descriptive headings. A consistent structural template across all units will also make the course easier to follow. This is a relatively low-effort change with meaningful impact on usability.

5. Content overlap and differentiation from related courses: A small number of respondents noted overlap between this course and "Entrepreneurship and Innovation in Advanced 5G Technologies," as well as some internal repetition of frameworks. Some foundational elements appear in both courses by design, as each course is structured to function as a standalone learning experience. This ensures that learners who enroll in only one course still acquire the

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necessary baseline knowledge. So, limited repetition is intentionally used as reinforcement to support knowledge retention and ensure continuity. While there are thematic similarities, the courses differ in focus and depth. One emphasizes foundational entrepreneurial skills, while the other advances into innovation processes and application within advanced 5G contexts. A final audit the against related courses in the program to ensure clear differentiation, and to streamline any internally redundant sections will be made. The course's distinct value proposition — focusing on entrepreneurial soft skills beyond the technology itself — should be made more explicit from the very start.

Scope	Refinement area	Adjustment
Whole course	Lecture Delivery	Targeted improvements in pacing voiceover, audio quality, segmentation of lectures , intro briefs, transitions, or key takeaways introduced.
Whole course	Audience Targeting & Profile Fit	Clearly define the intended learner profile at the start of the course.
Whole course	Engagement & Practical Components	Refine interactive elements, self-assessment exercises, scenario-based tasks and assignments to challenge learners to develop scalable, forward-looking solutions
Whole course	Course Structure & Navigation	Break long sections into smaller, clearly titled units with descriptive headings. Apply a consistent structural template across all units for easier navigation.
Whole course	Content Overlap & Differentiation	Audit content against related courses (especially "Entrepreneurship and Innovation in Advanced 5G Technologies"). Clarify the course's unique focus on entrepreneurial soft skills from the outset.

Table 9. Summary of refinement actions

4. Cross-Course Analysis

4.1. Common Feedback Trends

The cross-course analysis of the eight courses reveals a series of highly consistent feedback patterns that cut across subjects, instructional approaches, and learner profiles. Overall, learners rate the programme very positively, with average scores typically ranging between 4 and 5. Participants repeatedly highlight the clarity of explanations, the logical and coherent organisation of content, and the relevance of the topics addressed, particularly those related to 5G technologies, sustainability, IoT, and innovation. The introductory progression of the courses is widely perceived as effective, allowing learners to build knowledge gradually and confidently. As a result, the programme is consistently characterised as a strong and well-designed foundational learning ecosystem, particularly suitable for Bachelor- and Master-level audiences.

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A prominent trend emerges when satisfaction is analysed by academic profile. Bachelor students report the highest levels of satisfaction, followed closely by Master students, whose evaluations remain stable and positive across courses. In contrast, PhD students consistently express lower satisfaction and greater variability in their responses. Qualitative feedback from doctoral learners frequently indicates that the courses are perceived as too basic or overly theoretical, with insufficient advanced depth and limited alignment with their specific research interests. This pattern points to a clear strategic conclusion: while the programme performs very well for introductory and professional upskilling purposes, PhD-level learners are not the primary target audience of the current content design.

Feedback also reveals differences in perceived quality between courses. Network Architecture and Protocols, IoT/Industry 4.0/Smart Cities, and Green Skills stand out as particularly strong, benefiting from clear structure, updated content, high explanatory clarity, and the inclusion of valuable case studies. These elements significantly enhance perceived usefulness and learner engagement. By contrast, courses such as Introduction to Advanced 5G Technologies, Digital Skills for Beyond 5G, and Entrepreneurial Skills for Beyond 5G show greater dispersion in ratings and recurrent negative comments. These are often related to structural issues, pacing problems, assessment overload, and the extensive use of AI-generated narration.

Across all eight courses, learners repeatedly identify several programme-wide deficiencies. The most dominant negative theme concerns the use of AI voice narration, which is commonly described as monotonous, prone to pronunciation errors and audio glitches, and detrimental to concentration and engagement. Assessment design is another frequent source of frustration, with quizzes described as excessively long, repetitive, or technically flawed, sometimes requiring learners to restart entire assessments after a single mistake. In addition, students consistently express a desire for more practical application, including hands-on activities, laboratories, real-world examples, and smaller guided tasks. Many learners also report a mismatch between workload and ECTS allocation, as well as structural inconsistencies in module quality, navigation, and content organisation.

Course Feedback Report from KAU

Mr. Mohammad Rajiullah from KAU has conducted face-to-face evaluations with the students who have taken the courses, and this provides further valuable material for assessment and analysis, in addition to the online surveys completed by the other students. As can be seen, these results are consistent with the conclusions drawn from the analysis of the surveys. This report presents feedback collected from six PhD students regarding the WP2 courses. The participants come from diverse research backgrounds and are at different stages of their doctoral studies, which provides a broad and representative range of perspectives. Overall, the feedback is positive, with participants generally describing the courses as useful, relevant, and easy to follow. Many courses were found particularly engaging when their content aligned closely with the students' individual research interests. At the same time, the feedback highlights several areas where improvements could enhance the overall learning experience, especially in terms of consistency, engagement, assessment design, workload, and platform usability.

One of the most recurring observations concerns course design and structure. While some courses provide a clear introduction outlining objectives, learning outcomes, workload, and overall organization, others lack this information at the beginning. Participants emphasized that clear introductory framing is important for setting expectations and helping learners plan their time effectively. As a result, the report suggests that all WP2 courses should adopt a standardized introductory format that clearly communicates the purpose of the course, expected learning outcomes, estimated workload, and structural overview.

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Regarding learning materials and presentation, the content itself was generally appreciated, but the way it is delivered was seen as an area with significant room for improvement. Several videos were described as static or visually unengaging, which reduced learner motivation. Participants suggested incorporating more dynamic elements, such as improved slide design, visualizations, animations, and interactive components, to create a more engaging learning experience. Presentation style was also considered important. Although AI-generated voice was considered acceptable in some limited contexts, there was a clear overall preference for a natural human voice and a stronger human presence in the videos. Participants felt that human delivery, including natural speech and body language, will significantly improve engagement and comprehension.

Accessibility was another issue raised in the feedback. Some courses do not consistently provide transcripts for video materials, which can limit accessibility and make content review more difficult. The report therefore recommends that transcripts should be made available for all video-based course materials to ensure inclusiveness and support different learning preferences.

Assessment design and workload emerged as one of the most critical areas for improvement. Participants noted substantial inconsistencies across courses in terms of assessment formats, the number of questions, the number of permitted attempts, and the overall assessment strategy. In particular, assessments that were highly granular and organized section by section were viewed as less effective and unnecessarily demanding. There were also concerns about the total volume of questions and mini-projects in some courses, with several students reporting that the workload exceeded their expectations for a 2-credit course. In addition, the perceived effort required varied significantly between courses, suggesting a need for better alignment between learning activities, assessments, and assigned credits.

The feedback also points to issues of coherence across the WP2 course portfolio. Participants observed content overlap between several courses, especially within the introductory modules. The “Introduction to 5G” course was specifically mentioned as containing material that is repeated across multiple courses. While some overlap is understandable, the report indicates that excessive repetition can reduce efficiency and learner engagement. A more coordinated approach to curriculum design could help clarify the relationships between courses and minimize redundancy.

Platform usability and navigation were also discussed. Participants identified several practical improvements that could enhance the learner experience, such as ensuring that hyperlinks in course descriptions are clickable, providing metadata like video duration to support time management, and improving progress tracking. Learners expressed a strong interest in being able to see which videos they have already watched, how much of the course they have completed, and which assessments they have attempted.

Finally, course-specific feedback highlights both strengths and weaknesses. The course on Advanced 5G Technologies received criticism for overlapping content, less engaging presentation, mismatches between titles and content, and reliance on AI-generated voice. In contrast, the Network Architecture and Protocol course was praised for its clear introduction and preferred assessment style. The IoT courses were generally seen as well structured, although participants noted the need for stronger introductory framing and clearer justification for the selection of specific application areas. Courses focused on energy efficiency, sustainability, and green skills were received particularly well, especially when aligned with the participants’ research interests.

In conclusion, the report indicates that the WP2 courses have a solid foundation and are widely regarded as relevant and valuable. Nevertheless, it identifies clear priorities for enhancing consistency, pedagogical quality, and user experience. These include clearer and more uniform

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course introductions, consistent provision of transcripts, more engaging and human-centered learning materials, improved assessment standardization, better alignment between workload and credits, reduced overlap across courses, and enhanced platform usability. The feedback provides a constructive and actionable basis for further refinement of the WP2 course portfolio and for improving both learner satisfaction and educational quality.

4.2. Pedagogical Insights

Taken together, the feedback across all courses supports several clear pedagogical conclusions. First and foremost, the programme is exceptionally strong in providing breadth rather than depth. It offers learners a coherent and holistic introduction to advanced 5G ecosystems, sustainability, green ICT, IoT applications, and innovation and entrepreneurship. This broad conceptual grounding is highly valued by non-expert learners and those seeking general upskilling or orientation within the field. However, the programme does not provide the level of advanced practical or methodological depth required by research-oriented learners, and consequently does not meet PhD-level expectations.

A second key insight concerns instructional design consistency. While some modules are well structured, engaging, and pedagogically sound, these coexist with others that feature overlong videos, text-heavy or repetitive content, and inconsistencies in navigation and instructional guidance. This unevenness creates variability in the learning experience and reduces the overall coherence of the programme from a learner perspective.

Assessment practices further affect learning quality. The current quiz-centric approach increases cognitive load without proportional pedagogical benefit and often leads to frustration rather than reinforcement of learning outcomes. From a modern pedagogical standpoint, the assessment strategy does not align well with microlearning principles or learner-centred design, especially in digital education contexts.

Engagement is also strongly influenced by the degree of perceived human presence. Courses that include human narration, guest lecturers, or visible instructors consistently trigger higher emotional and cognitive engagement. In contrast, courses relying exclusively on AI-generated narration tend to underperform in terms of learner motivation, attention, and satisfaction.

Finally, the lack of systematic real-world application emerges as one of the most significant pedagogical gaps. Learners across profiles express a clear expectation for practice-based learning, applied tasks, and realistic case studies that will allow them to translate theoretical knowledge into concrete skills and professional competences.

4.3. Technical and Delivery Lessons Learned

The analysis of learner feedback also highlights several technical and delivery-related lessons that require strategic attention. The extensive reliance on AI-generated narration should not be maintained as the primary content delivery mode. The feedback indicates that engagement and satisfaction are adversely affected. Replacing AI narration with human instructors, or at minimum ensuring professional-grade AI voices with flawless pronunciation and audio quality, will likely result in a substantial improvement in learner experience.

Assessment infrastructure and quiz design require urgent revision. Quizzes should be shorter, more focused, and free of repetition, with clearly defined and technically robust multiple-answer logic. Allowing partial progress saving, and avoiding full quiz restarts after minor errors will significantly reduce frustration and cognitive overload.

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Another key lesson concerns the need for programme-wide standardisation. Establishing common templates for module structure, video duration, workload expectations, assignment instructions, and navigation conventions will improve coherence and reduce perceived fragmentation across courses. Such standardisation will also facilitate quality assurance and scalability.

In terms of content delivery, the systematic integration of practice-based learning is essential. Laboratories, simulations, guided exercises, micro-PBL cases, and analyses of real data were either under-represented or not consistently implemented across courses, indicating a need for further development. These elements should be aligned across courses rather than introduced sporadically.

Finally, audiovisual quality issues represent a largely solvable technical challenge with high impact. Learners report repeated slide content, occasional visual or icon loading errors, and audio glitches that negatively affect retention and concentration. Addressing these issues through improved production quality and technical validation will significantly enhance overall learning effectiveness.

4.4. Alignment with Project Objectives

The findings derived from the cross-course analysis demonstrate a strong overall alignment between the programme and the core objectives of the 5G-DiGITs project, while also highlighting specific areas where refinements in implementation could further strengthen impact and coherence.

First, the programme aligns closely with the objective of fostering new, innovative, and multidisciplinary approaches to teaching and learning. The curriculum successfully integrates advanced 5G technologies with sustainability, green skills, IoT, digital manufacturing, and entrepreneurship, offering learners a multidisciplinary perspective that reflects the complexity of contemporary digital and green transitions. The strong conceptual structure, clear progression, and broad thematic coverage confirm that the programme provides a coherent and innovative educational framework suitable for both higher education and vocational education and training contexts. However, the feedback also indicates that the innovative intent will benefit from a more systematic integration of problem-solving scenarios, simulations, and hands-on activities in order to fully translate conceptual innovation into applied learning experiences.

In relation to stimulating a sense of initiative and entrepreneurial attitudes, mindsets, and skills, the programme shows partial but meaningful alignment. Courses addressing entrepreneurial and innovation topics are perceived as relevant and conceptually valuable, particularly when supported by case studies. This supports the objectives of promoting entrepreneurial thinking in line with the Entrepreneurship Competence Framework [EntreComp]. Nevertheless, learners would prefer more applied entrepreneurship tasks and real-world problem contexts distributed through the courses. Strengthening interaction with industry experts, entrepreneurs, and practitioners, and embedding practice-based entrepreneurial activities more systematically, will further reinforce the project’s ambition to foster initiative and innovation-driven mindsets.

The objective of fostering the setting up of incubators within education and training institutions is conceptually supported by the programme’s emphasis on entrepreneurship, innovation ecosystems, and startup culture within advanced 5G and green technology domains. While the accelerator and incubation dimensions are not directly reflected within the individual course structures, the curriculum provides a solid knowledge base that underpins such initiatives. To enhance alignment, clearer links between course content and the transnational accelerator

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programme could be established, enabling learners to more explicitly connect educational activities with incubation and startup development pathways.

With respect to fostering corporate social responsibility, the alignment is particularly strong. Sustainability, green ICT, energy efficiency, and environmental considerations are consistently embedded across the programme, notably within the Green Skills and Green IoT-related courses. Learners recognise the relevance of these themes and their contribution to sustainable development objectives. This confirms that the curriculum effectively integrates corporate social responsibility principles into technical and digital education, supporting awareness of environmental protection and responsible innovation.

The programme also aligns well with the objective of supporting skills development in deep tech domains. Courses covering Sustainable 5G, Green IoT, Digital Manufacturing, and Native AI provide learners with broad exposure to key deep tech areas identified as strategically important. Collaboration with industry partners and the emphasis on emerging technology trends contribute to addressing skills needs in these domains. However, learner feedback indicates that deeper practical engagement and advanced skill application will be necessary to fully meet the expectations of highly specialised or research-oriented learners, particularly at PhD level.

Regarding the objective of improving the quality and relevance of skills developed and certified through education and training systems, the programme demonstrates strong alignment in terms of relevance and topicality. Learners consistently value the up-to-date nature of the content and its connection to current industry developments beyond 5G. At the same time, issues related to assessment design, workload imbalance, and instructional consistency undermine the perceived quality of certification. Addressing these issues through redesigned assessment strategies and standardised module structures will significantly enhance alignment with this objective.

The objective of facilitating the flow and co-creation of knowledge between stakeholders is partially supported by the programme's multidisciplinary design and its orientation towards industry-relevant content. However, the feedback suggests limited visibility of interactive knowledge exchange mechanisms within the learning experience itself. Greater integration of collaborative activities, industry-driven case studies, guest lectures, and shared platforms for learner interaction will strengthen co-creation and cross-sectoral knowledge flow among higher education institutions, VET providers, research organisations, and industry partners.

Finally, the programme contributes meaningfully to building and supporting effective and efficient higher education and vocational education and training systems. The strong foundational design, accessibility for non-expert learners, and breadth of topics support inclusivity and scalability across diverse educational contexts. Nonetheless, technical and delivery issues—such as inconsistent instructional design, overreliance on AI narration, and uneven audiovisual quality—limit overall efficiency and learner experience. Addressing these systemic issues will further enhance the programme's contribution to robust, connected, and future-oriented education and training systems aligned with labour market needs.

In summary, the programme demonstrates substantial alignment with the strategic objectives of the 5G-DiGITs Alliance project. While the conceptual and thematic foundations are strong, closer alignment between pedagogical implementation and project ambitions - particularly in practice-based learning, assessment design, and stakeholder engagement - will maximise impact and long-term sustainability.

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5. Conclusions and Future Improvements

This deliverable documented the transition of the 5G-DiGITs curriculum from a designed framework to a pilot-tested and refined learning offer implemented in a shared digital environment. The pilot showed that the curriculum is pedagogically robust, thematically relevant, and structurally coherent, especially for Bachelor- and Master-level learners in ICT and related fields, while also revealing recurring challenges that require attention in future iterations. Overall, the evidence confirms that the curriculum provides a solid foundation for cross-sectoral education in advanced 5G, digital, green, and entrepreneurial skills, but also underlines the need for continuous refinement to optimise usability, engagement, and alignment with diverse learner profiles.

At course level, the pilot has validated the core design choices made in D2.2. Across the eight courses, learners consistently rated **the clarity of explanations, the organisation of modules, and the relevance of topics as strong or very strong.** Quantitative results show medium-to-high average scores, with particular strengths in conceptual grounding, alignment between learning outcomes and activities, and the perceived usefulness of case-based and problem-based components. The systematic use of modular structures, explicit learning outcomes, and digital self-evaluation tools has proven effective for self-paced learning and for integrating the curriculum into different institutional contexts.

The cross-course analysis in Section 4 also **identifies recurring weaknesses that guide future improvements**. The most prominent relate to delivery quality and workload balance rather than content relevance. Learners frequently reported overly long video lectures, AI-generated narration perceived as monotonous, dense slides, and quizzes that are sometimes too long, repetitive, or technically flawed. In several courses, students felt that the overall effort was high for 2 ECTS, especially where quizzes and case-study tasks combined into a heavy workload. These findings indicate that next iterations prioritise audiovisual quality, assessment proportionality, and internal workload balancing while preserving the existing academic strengths.

A second cross-cutting conclusion concerns **the balance between theoretical coverage and applied practice**. Learners value the breadth and depth of conceptual material – especially in advanced 5G architectures, sustainability, cybersecurity, and entrepreneurship – but express a strong demand for more guided, hands-on activities and clearer real-world examples. Case studies and PBL components are generally viewed as meaningful, yet in some instances require more explicit scaffolding, clearer task descriptions, and tighter integration with earlier units. Strengthening the theory–practice connection through additional short applied tasks, structured examples, and concise synthesis activities is thus a key refinement direction.

Finally, a third conclusion relates to **audience targeting and profile fitness**. The pilot confirms very good fit for Bachelor and Master students, who typically report high satisfaction and positive perceived learning gains. By contrast, PhD students with advanced technical backgrounds or specialised research interests often perceive some courses as too introductory or not sufficiently aligned with their depth expectations. This suggests that the curriculum is best positioned as a high‑quality foundational offer for upper‑undergraduate, Master, and early‑career professional audiences, while doctoral‑level learners may require more advanced or tailored extensions. Future development should therefore clarify intendd learner profiles, signal expected prior knowledge more explicitly, and, where feasible, provide optional advanced materials without compromising coherence.

Methodologically, the pilot has shown **the value of combining structured learner feedback, LMS-based implementation evidence, and partner observations within the curriculum refinement cycle**. Although the sample was practice-oriented rather than statistically

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representative, and feedback collection was still ongoing for some courses at the time of analysis, the available data were sufficient to identify robust patterns and actionable priorities. The experience also highlights the importance of transparent communication of methodological limitations – such as sample size, institutional variation, and evolving datasets – when interpreting pilot outcomes.

Beyond the immediate refinement actions in Section 3, the findings of D2.6 point to longer-term development paths. One is the **design of complementary advanced modules or specialisation tracks in areas where PhD learners and highly specialised participants request greater depth, such as advanced network optimisation, cybersecurity for 5G/6G, or entrepreneurial execution**. Another is the **systematic use of learning analytics in future runs to monitor progression, engagement, and bottlenecks more precisely**. In parallel, **deeper collaboration with industry partners could enrich the curriculum through updated case studies, guest lectures, and authentic project briefs reflecting emerging deployment scenarios**.

In conclusion, the pilot confirms that **the 5G-DiGITs curriculum is sufficiently mature for wider deployment as a coherent, modular, and pedagogically sound learning offer supporting Europe's digital and green transitions**. The courses provide a strong foundation in advanced 5G technologies, digital and green skills, and entrepreneurial competences, while the identified refinement actions ensure that the curriculum can keep evolving in response to learner feedback and technological change.

6. References

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ANNEX I. Revised Curriculum Structure

1. Introduction to Advanced 5G Technologies

General Information

Course Title	Introduction to Advanced 5G Technologies
Learning Outcomes	• Understand the evolution of wireless communication networks and the key concepts of 5G

	• Identify the technologies, standards, and applications associated with 5G networks • Recognize the potential use cases of 5G in various industries
EQF Level	4
ECVET/ECTS Credits	2 ECTS
Total Learning Hours	60 hours (This aligns with the ECTS standard workload assumption of 25–30 hours per credit) Structure: • 20 hours of lectures, • 15 hours of practical exercises • 25 hours of independent study
Audience	Undergraduate or graduate students in engineering and Information and Communication technologies (ICT) with a basic networking background; early-career professionals and technical staff involved in mobile communications, sustainability, or digital infrastructure.
Prerequisites	Basic knowledge of networking theory and mobile network architecture
Language of Instruction	English
Coordinator	Nikos Passas

Table 10. General info for the course 'Advanced 5G Technologies'

Course Description

This course is part of the 5G-DiGITs curriculum and aims to provide comprehensive knowledge, skills, and abilities (KSAs) in advanced 5G technologies with a focus on sustainability and green skills. The curriculum aligns with Erasmus+ requirements and the KSA methodology. It covers technical skills, sustainability practices, and industry-relevant competencies for 5G professionals, introducing advanced 5G technologies, such as core vs access network, standardization, applications, use cases, demonstrators, etc.

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Detailed Learning objectives (instructor-oriented)

The following learning objectives are defined from an instructional perspective, providing pedagogical guidance for the delivery of each module.

Module	Learning Objectives
Module 1 **Evolution of mobile communications and fundamentals of 5G networks**	• Explain the evolution of mobile networks until 5G (2G, 3G, 4G) • Explain how standardization works in mobile network evolution and the planning towards 6G • Discuss the technological and performance differences between generations
Module 2 **Enabling technologies at the 5G access and core networks**	• Introduce the key aspects of the technological advancements that define 5G and 5G Advanced • Understand the basic technologies that shape 5G networks, including New Radio (NR), massive Multiple Input Multiple Output (MIMO), Network Functions Virtualization (NFV), Service Based Architecture (SBA), etc. • Clarify how these technologies can be exploited for the new innovative services
Module 3 **5G Applications, Vertical Challenges, and future trends**	• Give insights into the practical aspects of 5G infrastructures and experimentation platforms • Explain new applications and use case domains emerged in 5G era. • Understand limitations and implementation challenges in 5G use for specific vertical industries • Discuss current research efforts towards 6G

Table 11. Learning objectives for the course 'Advanced 5G Technologies'

Detailed Learning Outcomes (student-oriented)

By the end of this course, students will be able to:

Module	Learning Outcomes
Module 1 **Evolution of mobile communications and fundamentals of 5G networks**	• **Describe** the key technologies that defined the evolutionary steps from 2G to 5G and beyond • **Identify** technological components and their role in an end-to-end 5G system • **Explain** the procedure for technical contributions to standardisation and open-source bodies
Module 2	• **Analyse** functional and performance characteristics of the key technologies that defined the 5G era in telecommunications

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Enabling technologies at the 5G access and core networks	• **Target** relevant research topics and solutions towards 5G Advanced • **Explain** the main management and control processes in 5G systems
Module 3 **5G Applications, Vertical Challenges, and future trends**	• **Evaluate** potential new use cases for 5G and beyond networks • **Design** new applications and assess their potential in the ecosystem • **Demonstrate** innovative functionality and research results in lab/experimentation environments • **Understand** the business potential and the technological trends towards 6G

Table 12. Learning outcomes for the course 'Advanced 5G Technologies'

The alignment between modules and KSA items is presented in the table below.

Module	Knowledge (General Competencies)	Skills (Specific Competencies)	Abilities (Soft Competencies)
Module 1 **Evolution of mobile communications and fundamentals of 5G networks**	- Identify 2G, 3G, 4G evolution basics. - Understand the three 5G performance dimensions (eMBB, URLLC, and mMTC) - Clarify the fundamental design principles of 5G. - Understand the role of spectrum and frequency bands in network dimensioning and planning. - Understand the standardization process, the 3GPP structure, and the features in the key recent releases.	- Gain insights into the historical development of wireless networks and the driving factors behind each generation. - Develop an understanding of essential 5G technologies like massive MIMO, mmWave, and edge computing. - Be able to identify the role of organizations like 3GPP and ITU in setting 5G standards and how spectrum allocation impacts deployment.	- Compare different generations of wireless communication and explain the need for 5G advancements. - Be able to represent institutions in the standardization bodies. - Be able to assess the impact of new features and technologies in end-to-end network performance.
Module 2 **Enabling technologies at the**	- Understand critical technologies for 5G Radio, such as New	- Define research topics and open issues at the 5G	- Calculate the expected theoretical

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5G access and core networks	Radio, massive MIMO, and RAN functional split - Understand critical technologies for 5G Radio such as Service-Based approach, Service-Mesh approach, and network core openness.	radio access domain - Define research topics and open issues at the 5G radio access domain	performance in New Radio systems. - Apply and use API calls towards the experimental network core.
Module 3: 5G Applications, Vertical Challenges, and future trends	- Explain the role of 5G in innovative applications and use cases - Understand the implications and synergies required towards applying 5G technologies to vertical industries. - Get insights into pilot and large-scale deployments of 5G and beyond, especially in the EU. - Understand the emerging trends (6G vision, AI in 5G, and satellite integration).	- Evaluate how 5G is applied in industries such as healthcare, automotive, smart cities, and industrial automation. - Identify technical and regulatory challenges in implementing 5G networks and explore potential solutions. - Explore emerging trends such as 6G, AI-driven networks, and satellite integration in next-generation communication systems.	- Lead development groups for new 5G applications or installations. - Actively participate in teams for the development of next-generation networks.

Table 13. Alignment between KSA items and modules for the course 'Advanced 5G Technologies'

Detailed Modules and Units

MODULE	Module 1: Evolution of mobile communications and fundamentals of 5G networks
UNIT	**Unit 1: Mobile networks evolution towards 5G**
Learning Hours	10 hours
Learning Outcomes	By the end of this unit, students will be able to: • Understand the key evolutionary steps towards 5G

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	• Analyse performance requirements for mobile systems • Explain how standardization works in mobile networks
Teaching methods	Lectures, case study analysis, and independent study
Assessment methods	MCQs/SAQs (70%) to assess comprehension, Short Essays to test synthesis (30%) (Learning Outcome: LO1)
Prerequisites	None
UNIT	**Unit 2: Introduction to 5G and 5G Advanced systems**
Learning Hours	10 hours
Learning Outcomes	By the end of this unit, students will be able to: • Identify technological components and their role in an end-to-end 5G system • Describe the 5G technological and functional design • Recognize key features of 5G and 5G Advanced radio and core network
Teaching methods	Lectures, case study analysis, and independent study
Assessment methods	MCQs/SAQs (50%) to assess comprehension, Short Essays to test synthesis (50%) (Learning Outcome: LO1)
Prerequisites	Module 1- Unit 1

Table 14. Module 1 for the course 'Advanced 5G Technologies'

MODULE	**Module 2**: Enabling technologies at the 5G access and core networks
UNIT	**Unit 1: Enabling technologies at the 5G access network**
Learning Hours	10 hours
Learning Outcomes	By the end of this unit, students will be able to: • Understand the key technologies and protocols used at the radio access part of 5G networks. • Explain the basic functionalities and structure of New Radio, massive MIMO, and RAN functional split features. • Discuss how these technologies contribute to the advanced performance of 5G • Clarify how these technologies can be exploited for the new 5G services

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Teaching methods	Lectures, independent study, and practical exercises
Assessment methods	MCQs/SAQs (40%) to assess comprehension, Short Essays to test synthesis (60%) (Learning Outcome: LO2)
Prerequisites	Module 1
UNIT	**Unit 2: Enabling technologies at 5G network core**
Learning Hours	10 hours
Learning Outcomes	By the end of this unit, students will be able to: • Understand the key technologies and protocols used at the 5G network core. • Explain the basic functionalities and structure of the Service-Based approach, the Service-Mesh approach, and network core openness. • Discuss how these technologies contribute to the advanced performance of 5G • Clarify how these technologies can be exploited for the new 5G services
Teaching methods	Lectures, independent study, and practical exercises
Assessment methods	MCQs/SAQs (40%) to assess comprehension, Short Essays to test synthesis (60%) (Learning Outcome: LO2)
Prerequisites	Module 1

Table 15. Module 2 for the course 'Advanced 5G Technologies'

MODULE	**Module 3**: 5G Applications, Vertical Challenges, and future trends
UNIT	**Unit 1: 5G Applications and Use Cases**
Learning Hours	10 hours
Learning Outcomes	By the end of this unit, students will be able to: • Explain the new application and use case domains compared to previous generations • Give insights into the practical aspects of 5G • Describe a 5G demonstration for indicative vertical industries
Teaching methods	Lectures, independent study, and case study analysis
Assessment methods	MCQs/SAQs (40%) to assess comprehension, Short Essays to test synthesis (60%) (Learning Outcome: LO3)

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Prerequisites	Module 1 or a basic understanding of 5G technologies
UNIT	**Unit 2: Challenges and future trends**
Learning Hours	10 hours
Learning Outcomes	By the end of this unit, students will be able to: • Understand the 5G limitations and implementation challenges • Discuss current research efforts towards 6G • Understand the business potential and the technological trends towards 6G • Ethical considerations for 6G
Teaching methods	Lectures, independent study, and case study analysis
Assessment methods	MCQs/SAQs (40%) to assess comprehension, Short Essays to test synthesis (60%) (Learning Outcome: LO3)
Prerequisites	Module 1 or a basic understanding of 5G technologies

Table 16. Module 3 for the course 'Advanced 5G Technologies'

Learning and Teaching Methods

This course combines traditional and new teaching techniques to introduce the students to 5G technologies and use cases. The following techniques are combined in the learning process:

- Case Study Analysis: Industry-specific case studies of 5G rollouts in different environments will be analysed by the students to learn how the concepts are applied in real-life scenarios.
- Interactive Lectures: discussions, online Q&A, and demonstrations will be conducted in lectures to create an interactive learning environment where students are actively engaged in learning 5G technologies, applications, and use cases.
- Independent Study: Structured reading materials, research assignments, and online resources will help students take their learning outside the classroom, preparing them for exams and real-life applications.

This blended method ensures students get a strong theoretical foundation while developing hands-on skills in advanced digital capabilities for Beyond 5G technologies.

Work-Based Learning

Work-based learning includes short essays and independent study, allowing learners to gain practical experience in 5G technologies. These experiences enable students to be capable of converting theoretical knowledge into practical skills, ready for entry into professional careers in advanced 5G technologies and installations.

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Digital Competencies

The course emphasises the development of the following digital skills:

- **Network simulation and virtualisation**: Students will engage with software for 5G network simulation, virtualised environments, and network slicing techniques to understand the structure and behaviour of next-generation network systems. Examples: ns2, MATLAB, Simu5G.
- **E-learning and collaborative ICT tools**: Throughout the course, students will engage with digital learning platforms and collaborative tools, supporting teamwork, communication, and a fully connected learning experience. Example: Moodle.
- **Mobile applications design**: The course introduces platforms used for designing and implementing new 5G applications in various fields, exposing the students in new employment areas.

Assessment and Feedback Mechanism

The assessment methods utilised in this course aim to evaluate students' knowledge, skills, and competencies in an integral and well-rounded manner. The assessment aligns with the learning results and allows students to demonstrate their expertise in the most significant areas of the course. The assessment methods include the following:

- **Multiple-Choice Questions (MCQs)** will be used to assess students' understanding of foundational principles related to 5G technologies, standardization, applications, and use cases. MCQs are designed to test recall and application of master principles.
- **Short Answer Questions** will allow students to display their ability to give brief answers and apply what they know to specific situations in 5G technologies and applications.
- **Short Essays/Reports** will allow students to go in-depth about a specific topic, critically analysing current trends or challenges in 5G technologies and offering well-reasoned arguments based on evidence.

The primary assessment methods emphasise scalability and automation, with MCQs, short answers, and structured problem-solving accounting for most grading weight. Project work and case studies may be offered optionally for learners in instructor-supported contexts or as capstone activities.

The feedback mechanisms will be the following:

- MCQs will be provided with immediate feedback to help students identify correct and incorrect responses.
- Instructor feedback for written exercises (e.g., essays, reports) will be given as personalised comments about strengths and weaknesses.
- The instructor will also provide case study feedback, allowing students to refine their analysis and recommendations.

Project feedback will be provided periodically throughout the process, updating students on their progress and advising them on the final submissions.

Recommended readings

Module 1: Evolution of mobile communications and fundamentals of 5G networks

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- Kabalci, Y. (2019). 5G Mobile Communication Systems: Fundamentals, Challenges, and Key Technologies. In: Kabalci, E., Kabalci, Y. (eds) Smart Grids and Their Communication Systems. Energy Systems in Electrical Engineering. Springer, Singapore. https://link.springer.com/chapter/10.1007/978-981-13-1768-2_10

Module 2: Enabling technologies at the 5G access and core networks

- E. Hossain and M. Hasan, "5G cellular: key enabling technologies and research challenges," in IEEE Instrumentation & Measurement Magazine, vol. 18, no. 3, pp. 11-21, June 2015, doi: 10.1109/MIM.2015.7108393.

Module 3: 5G Applications, Vertical Challenges and future trends

- O. O. Erunkulu, A. M. Zungeru, C. K. Lebekwe, M. Mosalaosi and J. M. Chuma, "5G Mobile Communication Applications: A Survey and Comparison of Use Cases," in IEEE Access, vol. 9, pp. 97251-97295, 2021, doi: 10.1109/ACCESS.2021.3093213.

Development of Soft Skills

The course integrates soft skills development through:

- **Active participation** during lectures, where the students will be encouraged to ask questions and express their views in various subjects related to the content of the course.
- **Problem-solving exercises** via case studies, debugging, and hands-on network simulations to develop critical thinking, adaptability, and decision-making.

Industry Collaboration and Internships

Telecom and technology collaborations provide rich learning opportunities from the industry and practical exposure. Where institutional partnerships and resources allow, students are encouraged to engage in the following:

- **Industry guest lectures** by industry experts provide perspectives on future-looking 5G technologies, use cases, installations, and future applications.
- **Problem-based learning** and business partner case studies expose the learners to real-world experiences, industry insights, and current solutions, thereby eliminating the learning experience gap that occurs for certain theoretical topics.
- **Networking and mentorship** with other professionals in the profession augment career growth and foster industry relationships.

These collaborative opportunities are not guaranteed and depend on the specific institutional and regional context. They are offered when feasible and aim to enhance learner engagement with applied, occupation-specific experiences in the digital sector.

Accessibility and Inclusivity

The course is designed to be inclusive and accessible to all learners, ensuring equal opportunities for participation and success.

- **Transcripts and subtitles** for video content provide accessibility for learners with hearing impairments and support those who prefer text-based learning.

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- Language support for non-native speakers, including **glossaries** of technical terms and AI-powered translation tools, facilitates comprehension for diverse learners.
- **Flexible assessment formats**, such as oral presentations, written reports, and practical demonstrations, accommodate different learning preferences and needs.
- Customizable learning pace and materials, including **downloadable content** and asynchronous learning options, allow students to engage with the material at their own speed.
- Dedicated support for learners with disabilities, such as **extended assessment time** and **alternative task formats**, ensures an equitable learning experience.

These strategies reflect principles of Universal Design for Learning (UDL), promoting access and engagement for all learners regardless of background or ability

ECVET/ECTS Credit Allocation

The total course is allocated 2 ECTS, distributed across modules as follows:

- Module 1: 0.66 ECTS (20 hours)

- Module 2: 0.66 ECTS (20 hours)

- Module 3: 0.66 ECTS (20 hours)

Additional information (optional)

Abbreviation	Full Form
2G	Second Generation (Mobile Networks)
3G	Third Generation (Mobile Networks)
4G	Fourth Generation (Mobile Networks)
5G	Fifth Generation (Mobile Networks)
6G	Sixth Generation (Mobile Networks - Future)
AI	Artificial Intelligence
API	Application Programming Interface
ECTS	European Credit Transfer and Accumulation System
eMBB	Enhanced Mobile Broadband
EU	European Union
ICT	Information and Communication Technologies
ITU	International Telecommunication Union

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KSA	Knowledge, Skills, and Abilities
LO	Learning Outcome
MCQ	Multiple Choice Question
MIMO	Multiple Input Multiple Output
mmWave	Millimeter Wave
mMTC	Massive Machine-Type Communications
NFV	Network Functions Virtualization
NR	New Radio
RAN	Radio Access Network
SAQ	Short Answer Question
SBA	Service-Based Architecture
UDL	Universal Design for Learning
URLLC	Ultra-Reliable Low Latency Communication
WP	Work Package (in project context)
ns2	Network Simulator 2
Simu5G	Simulation platform for 5G networks

Table 17. List of Abbreviations for the course 'Advanced 5G Technologies'

2. Network Architecture and Protocols

General Information

Course Title	**Network Architecture and Protocols**
DoA Learning Outcomes	• Comprehend the architecture and components of 5G networks (LO1) • Understand network slicing, virtualization, and key protocols in 5G networks (LO2) • Apply knowledge of network security and privacy in 5G contexts (LO3)
EQF Level	6

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ECVET/ECTS Credits	2 ECTS
Total Learning Hours	60 hours (This aligns with the ECTS standard workload assumption of 25–30 hours per credit) Structure: • 20 hours of lectures, • 15 hours of practical exercises • 25 hours of independent study
Audience	Undergraduate or graduate students in engineering, ICT, or environmental disciplines; early-career professionals and technical staff involved in telecommunications, sustainability, or digital infrastructure
Prerequisites	• Basic knowledge of networking concepts • Basic knowledge of digital communication systems
Language of Instruction	English
Coordinator	Giuseppe Caso (KAU), Dionysia Triantafyllopoulou (TUC)

Table 18. General info for the course 'Network Architecture and Protocols'

Course Description

This course is part of the 5G-DiGITs curriculum and aims to provide comprehensive knowledge, skills, and abilities (KSAs) on Network Architecture and Protocols in 5G and Beyond-5G (B5G) communication systems.

The curriculum aligns with Erasmus+ requirements and the KSA methodology. It covers technical skills, practices, and industry-relevant competencies for 5G professionals. Key covered topics include:

- The evolution of mobile networks from 1G to 5G and their impact on society.
- 5G air interface and end-to-end architecture, including New Radio (NR), Radio Access Network (RAN), and Core Network (CN).
- 5G protocols, including the ones used in the Service-Based Architecture (SBA) model for the 5G CN.
- 5G Quality of Service (QoS) architecture and Network Slicing, which enable customized services.
- The role of Software-defined Networking (SDN), Network Function Virtualization (NFV), and Multi-access Edge Computing (MEC) in 5G systems.
- 5G security and privacy challenges, including encryption, authentication, and threat mitigation solutions.

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- The integration of Artificial Intelligence (AI) and Machine Learning (ML) in Beyond-5G (B5G)/6G system design and optimization.
- Future trends in the transition towards B5G/6G systems, in terms of emerging technologies and use cases.

Through a mix of theoretical lessons and hands-on activities, students will develop the KSAs necessary to work in 5G/B5G/6G network design, implementation, and management. The curriculum incorporates real-world case studies and problem-solving exercises to prepare students for industry challenges.

Detailed Learning objectives (instructor-oriented)

Module	Learning Objectives
Module 1 **Introduction to 5G Networks**	Enable students to: • Understand the historical evolution of mobile networks and the role of 5G • Identify the key components of the 5G architecture • Identify and compare key 5G use cases and applications
Module 2 **5G Radio Interface and RAN**	Enable students to: • Understand the spectrum allocation and frequency bands used by 5G systems • Describe 5G NR, including adopted resource grid, waveform, and modulation options • Identify the different 5G RAN deployment modes and their impact on users’ QoS/QoE performance • Describe privacy/security challenges in 5G RAN
Module 3 **5G CN and Network Slicing**	Enable students to: • Understand 5G CN and the SBA model • Describe the 5G QoS architecture and network slicing, along with their impact on service delivery and performance • Describe privacy/security challenges in 5G CN
Module 4 **B5G/6G Concepts and Future Trends**	Enable students to: • Identify B5G/6G technological advancements and use cases • Explore the integration of AI/ML in B5G/6G

Table 19. Learning objectives for the course ‘Network Architecture and Protocols’

Detailed Learning Outcomes (student-oriented)

By the end of this course, students will be able to:

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Module	Learning Outcomes
Module 1 **Introduction to 5G Networks**	• Understand the mobile cellular system evolution, with a focus on 5G and its key components • Critically evaluate mobile system design rationale and evolution
Module 2 **5G Radio Interface and RAN**	• Understand 5G NR and RAN, spectrum allocation, transmission/reception protocols • Analyse how 5G NR/RAN design and configuration affect users' QoS/QoE performance • Evaluate 5G RAN security and privacy challenges Critically evaluate 5G end-to-end performance and bottlenecks, and possible improvement solutions
Module 3 **5G CN and Network Slicing**	• Understand 5G CN, QoS architecture, network slicing, and their enablers, e.g., SDN/NFV and MEC • Analyse how to leverage the above components for service delivery and performance enhancement • Evaluate 5G CN security and privacy challenges Critically evaluate 5G end-to-end performance and bottlenecks, and possible improvement solutions
Module 4 **B5G/6G Concepts and Future Trends**	• Knowledge of B5G/6G advances in terms of key envisioned technologies and use cases • Understand how to apply AI/ML techniques for B5G/6G system optimization Enhance long-term strategic thinking towards B5G/6G research and innovation

Table 20. Learning outcomes for the course 'Network Architecture and Protocols'

The alignment between modules and KSA items is presented in the table below.

Module	Knowledge (General Competencies)	Skills (Specific Competencies)	Abilities (Soft Competencies)
Module 1 **Introduction to 5G Networks**	**5G Network Architecture:** Fundamental structure of 5G networks, including RAN and CN	**Analyse 5G network architecture:** End-to-end architectural view	**Network optimization problem solving:** Apply architectural understanding to identify conceptual

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	5G Standards: 3GPP and its role in defining 5G systems **5G Use Cases and Applications:** mobile broadband, low-latency, and massive IoT applications		optimization needs in early-stage 5G design **Research-oriented learning:** Explore foundational research literature and global standardization progress **Collaboration and communication:** Present general 5G concepts and use cases **Enhance long-term strategic thinking towards B5G/6G research and innovation:** Build awareness of emerging network demands and their long-term implications
Module 2 **5G Radio Interface and RAN**	**5G Network Architecture:** RAN components, e.g., the gNB. Differences between 4G, 5G Non-Standalone (NSA), and 5G Standalone (SA) deployments **5G Protocols:** Data plane and control plane protocol stacks, e.g., NR, RAN-RAN, and RAN-CN communication and functional split	**Analyse 5G network architecture:** Identify various elements of the 5G RAN, explain their key functions, and differentiate between deployments (e.g., NSA vs. SA) and functions (e.g., carrier aggregation vs. dual connectivity) **Analyse 5G QoS/QoE:** Use simulation or real	**Network optimization problem solving:** Analyse O-RAN configurations to suggest QoS/QoE improvements **Research-oriented learning:** Investigate mid-layer innovations (e.g., scheduling, numerology) in recent RAN-related studies **Collaboration and communication:**

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		measurements to analyze QoS/QoE metrics (e.g., latency, throughput, reliability)	Discuss and defend design decisions for different RAN deployment scenarios
		Work with key 5G protocols: Understand 5G signalling, e.g., on the Radio Resource Control (RRC) layer (e.g., for user mobility)	**Enhance long-term strategic thinking towards B5G/6G research and innovation:** Reflect on physical layer challenges in future radio interfaces (e.g., THz, RIS)
		Evaluate 5G security and privacy: Identify threats in 5G, analysing risk factors and best practices (e.g., encryption, mutual authentication, and anomaly detection)	
Module 3 **5G CN and Network Slicing**	**5G Network Architecture:** 5GC components, e.g., the User Plane Function (UPF). Differences between 4G CN and 5G CN	- Evaluate how 5G is applied in industries such as healthcare, automotive, smart cities, and industrial automation.	**Network optimization problem solving:** Address optimization trade-offs in virtualized and sliced core networks
	5G Protocols: Data plane and control plane protocol stacks, e.g., RAN-CN and within-CN communication	- Identify technical and regulatory challenges in implementing 5G networks and explore potential solutions.	**Research-oriented learning:** Study emerging paradigms such as network-as-a-service (NaaS) and security-by-design in CN
	Network Slicing and Virtualization: How	- Explore emerging trends such as 6G,	

	network slicing can be deployed thanks to SDN/NFV technologies **Edge Computing and Cloud Integration:** The role of cloud-nativeness and MEC in 5G (e.g., deploy and orchestrate virtual network functions) **QoS and Traffic Management:** QoS management in 5G, traffic prioritization, and policy control **5G Security and Privacy:** 5G vulnerabilities (e.g., signalling storms and DDoS attacks), and solutions (e.g., zero-trust)	AI-driven networks, and satellite integration in next-generation communication systems.	**Collaboration and communication:** Coordinate discussions on end-to-end slicing policies and signalling schemes **Enhance long-term strategic thinking towards B5G/6G research and innovation:** Explore implications of cloud-native CN evolution, AI/ML-driven orchestration, and quantum-resilient security frameworks
Module 4 **B5G/6G Concepts and Future Trends**	**Towards 6G: Vision, Key Technologies, and Challenges:** B5G/6G evolution, IMT-2030 requirements and key enablers (e.g., THz, Open RAN, AI-nativeness, reconfigurable intelligent surfaces, and non-terrestrial networks)	**Analyse 5G QoS/QoE performance bottlenecks towards enhanced B5G/6G system design**	**Network optimization problem solving:** Analyse end-to-end bottlenecks in 5G networks and extrapolate solutions for future B5G/6G architectures **Research-oriented learning:** Explore emerging research domains such as THz propagation, RIS configuration, and NTN integration **Collaboration and communication:**

		Lead discussions on disruptive 6G enablers and articulate trade-offs in visionary proposals **Enhance long-term strategic thinking towards B5G/6G research and innovation:** Formulate and evaluate plausible scenarios and technology roadmaps beyond IMT-2030

Table 21. Alignment between KSA items and modules for the course 'Network Architecture and Protocols'

Detailed Modules and Units

MODULE	Module 1: Introduction to 5G Networks
UNIT	**Unit 1: Evolution of Mobile Networks**
Learning Hours	4 hours (1.5h Lectures, 1h Exercises, 1.5h Independent Study)
Learning Outcomes	• Explain the development of mobile systems, from 1G to 5G • Compare the technical and business drivers for each generation • Identify the impact of 5G on digital transformation and industries
Teaching methods	Lectures, comparative analysis, and discussion-based learning
Assessment methods	Short essays, MCQs, group discussions
Prerequisites	None
UNIT	**Unit 2: Key Components of the 5G Architecture**
Learning Hours	4 hours (1.5h Lectures, 1h Exercises, 1.5h Independent Study)
Learning Outcomes	• Identify and explain the 5G core and RAN components • Describe cloud-nativeness in 5G

	• Compare the 5G architecture with legacy systems (e.g., 4G)
Teaching methods	Lectures, practical demonstrations, and interactive discussions
Assessment methods	Case study analysis, MCQs, practical exercises
Prerequisites	Unit 1 of Module 1

Table 22. Module 1 for the course 'Network Architecture and Protocols'

MODULE	**Module 2:** 5G Radio Interface and RAN
UNIT	**Unit 1: 5G Spectrum and Frequency Bands**
Learning Hours	6 hours (2h Lectures, 1.5h Exercises, 2.5h Independent Study)
Learning Outcomes	• Identify frequency bands allocated for 5G • Explain the impact of spectrum allocation on performance • Compare low-band, mid-band, and high-band spectrum applications
Teaching methods	Lectures, simulations, and/or data analysis
Assessment methods	MCQs, case study analysis
Prerequisites	Module 1
UNIT	**Unit 2: 5G New Radio**
Learning Hours	7 hours (2.5h Lectures, 2h Exercises, 2.5h Independent Study)
Learning Outcomes	• Understand the key features of 5G NR • Explain OFDM and beamforming techniques • Compare different modulation and coding schemes in 5G
Teaching methods	Lectures, practical demonstrations
Assessment methods	MCQs, practical exercises
Prerequisites	Module 1 / Unit 1 of Module 2

Table 23. Module 2 for the course 'Network Architecture and Protocols'

MODULE	**Module 3:** 5G CN and Network Slicing

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UNIT	**Unit 1: 5G CN and the SBA model**
Learning Hours	7 hours (2.5h Lectures, 2h Exercises, 2.5h Independent Study)
Learning Outcomes	• Explain the SBA model and its role in 5G CN • Compare traditional and service-based CN architectures • Analyse protocol interactions in the 5G CN
Teaching methods	Lectures, simulations
Assessment methods	MCQs, practical exercises
Prerequisites	Module 1 and Module 2
UNIT	**Unit 2: SDN/NFV and MEC in 5G**
Learning Hours	6 hours (2h Lectures, 1.5h Exercises, 2.5h Independent Study)
Learning Outcomes	• Understand the role of SDN and NFV in 5G networks • Examine the implementation of MEC for low-latency applications • Identify security risks in SDN/NFV/MEC applied to 5G (DDoS, virtualization vulnerabilities, edge security)
Teaching methods	Lectures, practical demonstrations
Assessment methods	MCQs, practical exercises
Prerequisites	Modules 1-2 / Unit 1 of Module 3

Table 24. Module 3 for the course 'Network Architecture and Protocols'

MODULE	**Module 4:** B5G/6G Concepts and Future Trends
UNIT	**Unit 1: Beyond 5G Evolutions – Towards 6G**
Learning Hours	5 hours (2h Lectures, 1h Exercises, 2h Independent Study)
Learning Outcomes	• Analyse the technological advancements paving the way for 6G • Compare 5G with potential 6G architectures and capabilities

	• Discuss future applications and technologies envisioned for B5G/6G systems (e.g., open RAN, non-terrestrial networks)
Teaching methods	Lectures, workshops, and group discussions
Assessment methods	Reading and discussion of research papers
Prerequisites	Modules 1-3
UNIT	**Unit 2: AI and Machine Learning in B5G/6G Systems**
Learning Hours	5 hours (2h Lectures, 1h Exercises, 2h Independent Study)
Learning Outcomes	• Understand the role of AI/ML in B5G/6G network optimization • Analyse use cases of AI/ML in B5G/6G systems, e.g., for network automated management (traffic prediction, resource allocation, anomaly detection) and/or performance enhancement (e.g., throughput prediction and forecasting)
Teaching methods	Lectures, discussion of research papers, and practical demonstrations
Assessment methods	Simulations and/or data-driven assignments
Prerequisites	Modules 1-3, Unit 1 of Module 4

Table 25. Module 4 for the course 'Network Architecture and Protocols'

All modules follow a consistent internal structure (learning objectives, guided content, self-evaluation, and applied examples) to support ease of navigation and reduce cognitive load.

Learning and Teaching Methods

This course adopts a mixed teaching approach to help students develop a comprehensive set of KSAs related to 5G network architecture and protocols. The main learning strategies are as follows:

- **Interactive Lectures:** Lectures are designed to be participatory, combining frontal teaching with Q&A sessions and group discussions around key topics related to 5G system architecture, protocol design, and performance. Short, guided technical walkthroughs (e.g. protocol flows, architectural decision points, or deployment trade-offs) are integrated within selected modules to strengthen theory–practice connection without increasing total workload.
- **Independent Learning:** Students are encouraged to deepen their understanding through assigned readings, curated resources, and reflective tasks. Independent study supports self-paced learning and helps students connect course content to their academic or professional interests. Independent study activities are scoped and linked to specific learning objectives, with guidance provided on expected depth and effort to support efficient self-paced learning.

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Work-Based Learning

Work-based learning (WBL) in this course is designed to enable students to gain practical exposure to problems typically faced in communication system design, deployment, and validation. The main WBL strategies are as follows:

- **Hands-on Technical Work:** Exercises and lab sessions, e.g., including analysis of data collected in real 5G networks/testbeds, enable students to enrich their practical understanding of the 5G systems, with a focus on how system features and configurations impact QoS/QoE performance.
- **Case-Based Learning:** Selected case studies on specific aspects of the 5G architecture and protocols enable students to connect the dots between theoretical system design and real-world system implementation and use. Case studies are particularly designed as focused analytical exercises aimed at reinforcing architectural reasoning and decision-making, rather than as large-scale or time-intensive projects.

These activities are embedded within the course structure and do not require placement in external workplaces. However, when institutional conditions permit, students may be encouraged to pursue **industry collaborations, field projects, or internships** to reinforce learning with hands-on experience in real operational settings.

Digital Competencies

This course empowers learners to develop advanced digital competencies tailored to the 5G/B5G architectures and protocols. Students will engage in advanced data analysis and digital environments for understanding fundamental concepts related to 5G systems. Key digital skill areas include:

- **Data Processing and Analytics:** Students will explore tools for analysing network QoS/QoE performance indicators, such as latency, packet loss rate, reliability, and throughput.
- **Simulation and Modelling Environments:** Students will work with digital tools for simulating 5G deployment scenarios and end-to-end network behaviour. Examples of such tools include MATLAB, Python-based frameworks, network simulators (e.g., ns-3, OMNeT++), and experimental data analysis platforms, depending on institutional availability. These activities are implemented in a guided and illustrative manner, focusing on concept validation and interpretation rather than extensive tool-specific training.

By the end of the course, students will not only understand 5G design and implementation principles on a theoretical level but will be also equipped with a digital toolkit that enable to enrich their practical measurement, analysis, and data-driven decision-making skills.

Assessment and Feedback Mechanism

The assessment strategy in this course is designed to evaluate students' understanding of concepts related to 5G network architecture and protocols. Assessments are aligned with both the modular learning outcomes and the KSA-based structure of the course. Formative self-evaluation quizzes are designed to remain proportionate to the 2 ECTS workload and to support learning consolidation rather than function as high-load summative assessments. Quiz length and frequency are therefore controlled to avoid repetition and excessive assessment density.

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The assessment formats used in this course include:

- **Multiple-choice Questions (MCQs),** for quick feedback and supporting knowledge retention. Where used, quizzes are intentionally short and focused, prioritising conceptual consolidation over volume, and avoiding repeated or overly detailed questioning.
- **Short Answer Questions,** allowing students to concisely articulate key concepts learned during the course.
- **Design/Problem-Solving Tasks and Case Study Analyses,** allowing students to design solutions for real-world 5G deployment and/or performance challenges.
- **Essays, Brief Reports and/or Presentations,** allowing students to deepen and share their critical reflection on specific topics.

Feedback is both formative and summative and includes:

- **Automated feedback** for MCQs.
- **Written feedback** on assignments and reports.
- **Peer feedback** for team-based activities.
- **Instructor feedback** during project development phases.

This multi-modal assessment system ensures that students are not only evaluated on their retention of knowledge but also on their **ability to analyse**, **create**, and **communicate** sustainability solutions within digital contexts

Recommended readings

The following readings are recommended to support learning in each module. These resources include foundational overviews, applied research, and state-of-the-art surveys relevant to 5G/B5G technologies. The course platform will provide links to open-access versions or institutional library access where available.

1. **Module 1 –** *ITU-R*, “Recommendation M.2380: IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond”, 2015.

https://www.itu.int/dms_pubrec/itu-r/rec/m/r-rec-m.2083-0-201509-i!!pdf-e.pdf

This ITU-R document defines the 5G development framework.

2. **Module 1 –** J. G. Andrews *et al.*, "What Will 5G Be?," in IEEE Journal on Selected Areas in Communications, vol. 32, no. 6, pp. 1065-1082, June 2014, doi: 10.1109/JSAC.2014.2328098.
   https://ieeexplore.ieee.org/document/6824752

This paper discusses several aspects related to 5G research and development, identifying key challenges prior to 5G standardization activities.

3. **Module 1 –** *5G-PPP,* “View on 5G Architecture”*, 2019.*
   https://5g-ppp.eu/wp-content/uploads/2020/02/5G-PPP-5G-Architecture-White-Paper_final.pdf

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This white paper provides a comprehensive overview of the 5G architecture, detailing both RAN and CN components.

4. **Modules 1 and 4 –** B. Bertenyi, "5G Evolution: What's Next?," in IEEE Wireless Communications, vol. 28, no. 1, pp. 4-8, February 2021, doi: 10.1109/MWC.2021.9363048.

https://ieeexplore.ieee.org/abstract/document/9363048

This paper outlines the future trajectory of 5G, emphasizing standardization efforts, key use case enhancements, and the challenges and opportunities in real-world deployments.

5. **Module 2 –** X. Lin *et al.*, "5G New Radio: Unveiling the Essentials of the Next Generation Wireless Access Technology," in IEEE Communications Standards Magazine, vol. 3, no. 3, pp. 30-37, September 2019, doi: 10.1109/MCOMSTD.001.1800036.

https://ieeexplore.ieee.org/abstract/document/8928165

This paper describes the fundamental concepts of 5G NR, explains the design of physical channels and reference signals, and shares the design rationale.

6. **Module 2 –** S. Ahmadi (2019). 5G NR: Architecture, technology, implementation, and operation of 3GPP new radio standards. Academic Press.

https://www.oreilly.com/library/view/5g-nr/9780128134023/

This book provides a comprehensive reference on 3GPP's NR standards (Release 15 and beyond), covering the underlying theory, functional descriptions, practical considerations, and implementation.

7. **Module 2 –** G. Liu, *et al.*, "5G Deployment: Standalone vs. Non-Standalone from the Operator Perspective," in IEEE Communications Magazine, vol. 58, no. 11, pp. 83-89, November 2020, doi: 10.1109/MCOM.001.2000230.

https://ieeexplore.ieee.org/abstract/document/9269939

This article analyzes and compares 5G SA and NSA deployment modes in terms of coverage, network capability, interworking between 4G and 5G, complexity and cost of network deployment, and the latest industry progress.

8. **Modules 2 and 3 –** W. Stallings (2021). 5G Wireless: A Comprehensive Introduction. Pearson.

https://elibrary.pearson.de/book/99.150005/9780136767282

This book presents a unified explanation of 5G key applications, technologies, and standards, with a focus on 5G CN and RAN elements.

9. **Modules 2 and 3** – I. Ahmad, *et al.*, "Overview of 5G Security Challenges and Solutions," in IEEE Communications Standards Magazine, vol. 2, no. 1, pp. 36-43, MARCH 2018, doi: 10.1109/MCOMSTD.2018.1700063.

https://ieeexplore.ieee.org/abstract/document/8334918

This article presents challenges and solutions for secure 5G systems.

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10. **Module 3 –** F. Z. Yousaf, *et al.*, "NFV and SDN—Key Technology Enablers for 5G Networks," in IEEE Journal on Selected Areas in Communications, vol. 35, no. 11, pp. 2468-2478, Nov. 2017, doi: 10.1109/JSAC.2017.2760418.

https://ieeexplore.ieee.org/abstract/document/8060513

This paper provides an overview of both NFV and SDN technologies with reference to the 5G networks, describing how the two technologies complement each other and how they are expected to drive 5G design and implementation.

11. **Module 3 –** J. Ordonez-Lucena, *et al.*, "Network Slicing for 5G with SDN/NFV: Concepts, Architectures, and Challenges," in IEEE Communications Magazine, vol. 55, no. 5, pp. 80-87, May 2017, doi: 10.1109/MCOM.2017.1600935.

https://ieeexplore.ieee.org/abstract/document/7926921

This article summarizes the key aspects that enable network slicing and the role of SDN and NFV technologies to address the realization of network slices.

12. **Module 4** – ITU-R, "Recommendation M.2160: Framework and overall objectives of the future development of IMT for 2030 and beyond", 2023.

https://www.itu.int/rec/R-REC-M.2160/en

This ITU-R document defines the ongoing 6G development framework.

13. **Module 4** – Z. Zhang *et al.*, "6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies," in IEEE Vehicular Technology Magazine, vol. 14, no. 3, pp. 28-41, Sept. 2019, doi: 10.1109/MVT.2019.2921208.

https://ieeexplore.ieee.org/document/8766143

This article presents a research-oriented vision of what 6G will be and describes usage scenarios and requirements.

14. **Module 4 –** K. B. Letaief, *et al.*, "The Roadmap to 6G: AI Empowered Wireless Networks," in IEEE Communications Magazine, vol. 57, no. 8, pp. 84-90, August 2019, doi: 10.1109/MCOM.2019.1900271.

https://ieeexplore.ieee.org/abstract/document/8808168

This paper discusses the role of AI in designing and optimizing 6G architectures, protocols, and operations.

15. **Module 4 –** H. Yang, *et al.*, "Artificial-Intelligence-Enabled Intelligent 6G Networks," in IEEE Network, vol. 34, no. 6, pp. 272-280, November/December 2020, doi: 10.1109/MNET.011.2000195.

https://ieeexplore.ieee.org/abstract/document/9237460

This article reviews the applications of AI techniques in 6G networks, highlighting future research directions and potential solutions.

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Development of Soft Skills

In addition to technical knowledge, this course emphasises developing **soft skills** essential for professionals working in 5G/B5G system design, implementation, deployment, and management. These competencies are woven throughout the course structure and are aligned with the **transversal abilities** identified in the KSA framework. Key soft skills addressed in the course include:

- **Critical thinking and ethical reasoning**: Through case studies and discussions on 5G real-world deployment and performance, students examine the impact of proper design and implementation of both 5G architecture and protocols, eventually evaluating the existing trade-off between different performance indicators.
- **Communication and collaboration**: Students engage in team-based activities such as data processing and analytics, as well as technical reading and discussion, thus enhancing their ability to collaborate and communicate their ideas and findings.
- **Adaptability and problem-solving**: Scenario-based exercises, such as designing QoS/QoE performance enhancement solutions, strengthen students' capacity to respond flexibly and creatively to evolving challenges.

These soft skills are integrated into the **assessment process** via team projects, case-based activities, presentations, and feedback cycles. While not always evaluated as standalone competencies, they are key to students' overall performance and readiness for **professional roles in 5G/B5G network design, implementation, and enhancement**.

Industry Collaboration and Internships

While this course is primarily developed as part of a research-driven Erasmus+ initiative focused on **online learning**, it is designed with a clear view of the **professional and industry contexts** in which digital skills related to 5G system architecture and protocols are increasingly relevant.

To encourage students' exposure to real-world applications of the course content, the following forms of **industry engagement are recommended**, though not formally integrated into the course delivery:

- **Guest lectures and expert panels**, particularly in asynchronous or recorded formats, can offer valuable perspectives from professionals in the course topics.
- **Case studies and problem-based scenarios** inspired by industry use cases and requirements help learners simulate challenges such as a proper 5G network configuration.
- **Internships or mentorships**, where accessible through the learner's home institution or professional network, are encouraged to deepen experience and apply course knowledge in context. However, such activities fall outside the scope of this course's core offering.
- **Selected security-related topics** (e.g. protocol vulnerabilities, virtualization risks, and zero-trust principles) may be offered as optional enrichment material, allowing interested learners to deepen their understanding without increasing mandatory workload.

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By working with realistic challenges and exploring best practices, students build the awareness and competencies to engage meaningfully in the broad ecosystem around 5G systems and networks.

Accessibility and Inclusivity

While the primary focus of this course is to deliver **high-quality, research-based content**, efforts have been made to ensure that the course is **as accessible and inclusive as reasonably possible** within the project's scope.

The course is delivered online and designed to accommodate a range of learners and learning styles, with the following recommended features and good practices:

- **Subtitles and transcripts** are included for video content, supporting both non-native English speakers and learners with hearing impairments.
- **Modular, asynchronous delivery** allows students to access and complete content at their own pace, supporting flexibility and individual learning preferences.
- **Clear, structured presentation** of materials supports comprehension and navigation, especially in self-paced learning environments. A course-level overview and module-level summaries are provided in the learning platform to support orientation, progression planning, and independent study in an asynchronous environment.
- **Language support tools**, such as glossaries and definitions of technical terms, are provided to assist learners from various academic or professional backgrounds.

While a full range of accessibility adaptations (e.g., advanced screen reader compatibility, multilingual versions, or extensive alternative formats) is not guaranteed at this stage, the course design considers **key barriers** that learners may face. It aims to minimise them within project constraints.

The project team encourages institutions or instructors implementing this course to adapt it further to meet local or institutional accessibility standards when possible.

ECVET/ECTS Credit Allocation

The 60 learning hours are distributed across different types of activities:

- **Lectures and instructional content**: 21.5 hours
- **Practical exercises and guided activities**: 15.5 hours
- **Independent study, reading, and assessment preparation**: 23 hours

The specific allocation of hours (e.g., 21.5h for lectures, 15.5h for exercises) is based on the complexity of the material, the balance between theoretical and applied learning, and the pedagogical intent to ensure adequate time for concept absorption and skill development.

The distribution of ECTS credits across modules is based on the relative weight and expected workload of each:

- **Module 1: Introduction to 5G Networks** – *0.33 ECTS (10 hours)*
- **Module 2: 5G Radio Interface and RAN** – *0.66 ECTS (20 hours)*
- **Module 3: 5G CN and Network Slicing** – *0.66 ECTS (20 hours)*

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- **Module 4: B5G/6G Concepts and Future Trends** – *0.33 ECTS (10 hours)*

This allocation reflects the expected time investment across **content acquisition, applied activities**, and **student-led learning**. Moreover, it takes into account feedback from prospective learners, with particular attention to maintaining proportional assessment effort and avoiding cumulative overload across quizzes and assignments.

3. IoT, Industry 4.0, and Smart Cities

General Information

Course Title	IoT, Industry 4.0, and Smart Cities
DoA Learning Outcomes	• Understand IoT in the 5G context (LO1) • Understand the role of IoT in 5G networks and its integration with Industry 4.0. (LO2) • Familiarize with IoT technologies used in Industrial environments (LO3)
EQF Level	6
ECVET/ECTS Credits	2 ECTS
Total Learning Hours	60 hours (This aligns with the ECTS standard workload assumption of 25–30 hours per credit) Structure: • 20 hours of lectures, • 20 hours of practical exercises • 20 hours of independent study
Audience	• Undergraduate and postgraduate students in relevant fields • Early-career professionals working in city planning, smart infrastructure, or digital innovation • Public sector employees and policymakers involved in urban development and sustainability initiatives • General audience with basic knowledge of urban systems or digital tools
Prerequisites	• Basic knowledge of telecommunications and networking • Basic programming skills • General technical proficiency
Language of Instruction	English

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Coordinator	Panos Gounas

Table 26. General info for the course 'IoT, Industry 4.0, and Smart Cities'

Course Description

This course is part of the 5G-DiGITs curriculum and is designed to provide comprehensive knowledge, skills, and abilities (KSAs) in the areas of IoT, Industry 4.0, and Smart Cities.

It aligns with Erasmus+ requirements and follows the KSA methodology, focusing on technical skills, practical experience, and industry-relevant competencies for future 5G professionals.

Key topics include:

- The fundamentals and evolution of the Internet of Things (IoT), including its technological roots and major application domains;
- IoT edge-device building blocks, including microcontrollers, sensors, firmware, and lightweight operating systems;
- IoT networking basics and communication technologies, including short-range, long-range, and cellular connectivity solutions;
- IoT networking and application protocols, including Wi-Fi, Bluetooth, Zigbee, LoRaWAN, 6LoWPAN, MQTT, CoAP, and ZeroMQ;
- Cellular IoT and 5G-enabled IoT, including LTE-M, NB-IoT, massive connectivity, low latency, network slicing, and edge computing;
- The principles and enabling technologies of Industry 4.0, with a focus on manufacturing transformation and Industrial IoT (IIoT);
- Smart manufacturing technologies, including automation, robotics, data-driven manufacturing, and AI integration in industrial systems;
- IIoT architectures and platforms, including industrial communication technologies, edge computing, fog computing, cloud platforms, and data integration;
- Deployment strategies, case studies, and sustainability aspects of IoT and Industry 4.0 in real-world industrial environments;
- Smart Cities concepts and infrastructure, including urban sustainability, innovation, stakeholder ecosystems, business models, urban data platforms, and interoperability.

Detailed Learning objectives (instructor-oriented)

Module	Learning Objectives
Module 1 **IoT in 5G context**	Enable students to • Explain the concept of the Internet of Things (IoT) and discuss its typical application areas. • Describe the characteristics of various communication technologies, including 5G, and evaluate their suitability for different use cases based on these characteristics.

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Module 2 **Industry 4.0 Technological and Vertical-specific Challenges**	Enable students to: • Identify the essential technical skills required to design, deploy IoT systems in industrial environments. • Analyse key technological challenges and solutions in implementing Industry 4.0 across different sectors. • Encourage thoughtful discussion about the ethical, environmental, social, and economic ramifications of deploying smart city technologies.
Module 3 **Smart Cities**	Enable students to: • Introduce the foundational concepts of Smart Cities, including their goals, evolution, and relevance to contemporary urban development. • Describe the technological elements that support smart cities, including cloud platforms, IoT, AI, data analytics, and smart infrastructure. • Assess students' ability to evaluate, design, or improve Smart City initiatives using strategic, interdisciplinary thinking. • Encourage thoughtful discussion about the ethical, environmental, social, and economic ramifications of deploying smart city technologies.

Table 27. Learning objectives for the course 'IoT, Industry 4.0, and Smart Cities'

Detailed Learning Outcomes (student-oriented)

By the end of this course, students will be able to:

Module	Learning Outcomes
Module 1 **IoT in 5G context**	• **Define** key components of an IoT system and identify appropriate application areas such as smart homes, healthcare, and industrial automation. • **Compare** communication technologies (e.g., Wi-Fi, LoRaWAN, 5G) using metrics like range, latency, and power efficiency, and select suitable technologies for specific IoT scenarios.
Module 2 **Industry 4.0 Technological and Vertical-specific Challenges**	• **Describe** IoT technologies and related use cases in the Industry 4.0 domain • **Explain** the key research challenges and the practical implications for the convergence of OT and ICT systems (5G)

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	• **Assess and interpret** real-time performance metrics of Industrial processes • **Design and analyse** data management and automation systems for manufacturing
Module 3 **Smart Cities**	• **Define and describe** the core principles, goals, and characteristics of Smart Cities • **Identify and explain** the key technologies used in Smart Cities, including IoT, AI, big data, and cloud computing. • **Analyse real-world examples** of Smart City projects and assess their effectiveness across different domains (e.g., mobility, energy, public services)

Table 28. Learning outcomes for the course 'IoT, Industry 4.0, and Smart Cities'

The alignment between modules and KSA items is presented in the table below.

Module	Knowledge (General Competencies)	Skills (Specific Competencies)	Abilities (Soft Competencies)
Module 1 **IoT in 5G context**	• Introduction to IoT: definition and core principles of IoT, its key components, and an overview of common IoT application domains • Communication technologies in IoT: Categories of communication technologies (short range, long range/LPWAN), overview of protocol stacks for constrained environments (e.g., MQTT, CoAP) • 5G for IoT: Key 5G features and their support for massive IoT deployment	• IoT System Analysis: • Analyse an IoT system's architecture and components, and identify the key technical and functional requirements of typical IoT applications. • Technology Evaluation: • Evaluate and compare communication technologies (e.g., Wi-Fi, LoRaWAN, NB-IoT, 5G) based on performance metrics such as range, latency,	• IoT System Analysis: Ability to analyse and break down an IoT system into its core components and define the functional and technical needs of various application contexts. • Technology Evaluation: Ability to assess and compare different IoT communication technologies based on key performance indicators, and recommend suitable technologies for specific use cases.

		energy efficiency, scalability, and bandwidth. Match appropriate technologies to real-world IoT use cases. • 3. Hands-on Experience: Set up basic communication between IoT devices using protocols like MQTT or CoAP.	• 3. Hands-on Experience: Ability to configure IoT devices and establish data communication using appropriate lightweight protocols (e.g., MQTT, CoAP).
Module 2 **Industry 4.0 Technological and Vertical-specific Challenges**	• **Fundamentals on IoT Technologies:** Understanding IoT systems, radio and protocol aspects, as well as IoT architecture and performance capabilities • **Industry 4.0 in manufacturing Ecosystem:** Acquire knowledge on the key Manufacturing challenges in the 5G and beyond era, as well as on the state of play of OT and ICT solutions applied in industrial environments.	• Experience in Data modelling for industrial processes • Practical use of Automation systems in CNC machine shop • Expertise in IoT technologies	• **Supporting Innovation in Manufacturing:** the ability to understand and design automation systems and data modelling features for the Manufacturing domain • **Analysing Industry-Specific Applications:** ability to assess performance results and metrics from monitoring systems, as well as the ability to set up requirements for the networks within an industrial environment
Module 3	• Understand the core concepts and	• Analyse Smart City case	• Communicate complex ideas

Smart Cities	objectives of Smart Cities • Identify the main technologies enabling smart urban solutions Recognize the role of data, connectivity, and infrastructure in smart city systems	studies using real data • Evaluate the impact of technology on urban stakeholders Design or assess smart solutions for areas like mobility, energy, and governance	clearly to diverse audiences • Collaborate effectively within multidisciplinary teams • Think critically and ethically about the societal implications of smart technologies

Table 29. Alignment between KSA items and modules for the course 'IoT, Industry 4.0, and Smart Cities'

Detailed Modules and Units

MODULE	**Module 1**: Understand IoT in the 5G context
UNIT	**Unit 1: Introduction to IoT and its typical application area**
Learning Hours	5 hours
Learning Outcomes	Students will be able to explain the fundamental concept of the Internet of Things (IoT), identify its key components, and describe common application areas such as smart homes, healthcare, industrial automation, and smart cities.
Teaching methods	Lectures and case studies
Assessment methods	MCQs, short essays
Prerequisites	None
UNIT	**Unit 2: IoT communication technologies and the role of 5G**
Learning Hours	15 hours
Learning Outcomes	Students will be able to compare communication technologies (e.g., Wi-Fi, LoRaWAN, 5G) using metrics like range, latency, and power efficiency, and select suitable technologies for specific IoT scenarios.
Teaching methods	Lectures and case studies
Assessment methods	MCQs, short essays
Prerequisites	Introduction to computer networking and basic programming skills

Table 30. Module 1 for the course 'IoT, Industry 4.0, and Smart Cities'

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MODULE	Module 2: Industry 4.0 Technological and Vertical-specific challenges
UNIT	**Unit 1: Industry 4.0 potential for Manufacturing**
Learning Hours	10 hours
Learning Outcomes	By the end of this unit, students will be able to: • Understand key challenges and recent evolutionary steps in manufacturing • Evaluate the role of data-driven and AI-based decision-making in optimising OT
Teaching methods	Lectures and case studies
Assessment methods	MCQs, short essays
Prerequisites	None
UNIT	**Unit 2: IoT technologies for Industrial environments**
Learning Hours	10 hours
Learning Outcomes	By the end of this unit, students will be able to: - Explain key IoT technologies - Apply the principles of IoT networks in industrial environments • - Evaluate the performance of industrial systems that utilize ICT technologies
Teaching methods	Lectures, presentation of related tools, and practical exercises
Assessment methods	MCQs, short essays
Prerequisites	None

Table 31. Module 2 for the course 'IoT, Industry 4.0, and Smart Cities'

MODULE	Module 3: IoT Smart Cities Module
UNIT	**Unit 1: Introduction to IoT Smart Cities**
Learning Hours	10 hours
Learning Outcomes	By the end of this unit, students will be able to: • Define what a Smart City is, including its various technology components and the interactions of those technologies

	• Define the sustainability term • Identify Key Technologies • Analyse Stakeholder Interactions
Teaching methods	Lectures and case studies
Assessment methods	MCQs, short essays
Prerequisites	None
UNIT	**Unit 2: Smart Cities Concept**
Learning Hours	**10 hours**
Learning Outcomes	By the end of this unit, students will be able to: • Describe use cases of smart city technologies for modern urban challenges, including public safety, transportation, sustainability, public works, and digital inclusion/equity. • Analyse Stakeholder Interactions
Teaching methods	Lectures and case studies
Prerequisites	None

Table 32. Module 3 for the course 'IoT, Industry 4.0, and Smart Cities'

Learning and Teaching Methods

This course combines traditional and new teaching techniques to attain a complete and real-world understanding of Industrial IoT systems. The following techniques are combined in the learning process:

- Problem-Based Learning (PBL): Students will work with real-world issues related to IoT, Industry 4.0, and manufacturing. This technique encourages critical thinking and experiential problem-solving.
- Case Study Analysis: Industry-specific case studies will be analysed by the students to learn how the concepts are applied in real-life scenarios.
- Interactive Lectures: discussions, online Q&A, and demonstrations will be conducted in lectures to create an interactive learning environment where students are actively engaged in learning Beyond IoT technologies and Industrial OT concepts.
- Independent Study: Structured reading materials, research assignments, and online resources will help students take their learning outside the classroom, preparing them for exams and real-life applications.
- Work-Based Learning: Students will apply theoretical principles to actual projects, including designing of Industrial IoT systems, evaluating metrics from industrial automation processes, and integrating ICT technologies to Industrial OT.

This blended method ensures students get a strong theoretical foundation while developing hands-on skills in advanced digital capabilities for Industrial IoT technologies.

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Work-Based Learning

- Basic understanding of urban systems (e.g., transport, energy, waste, public services)
- Familiarity with digital tools or concepts such as:
  - Internet of Things (IoT)
  - Data analytics
  - Cloud computing
  - Smart infrastructure
- Awareness of general challenges in urban development (e.g., sustainability, mobility, inclusivity)

Digital Competencies

This course aims to develop upper-level digital competencies for handling Industrial IoT technologies. Students will gain both theoretical knowledge and practical experience with a range of advanced tools and platforms across multiple domains:

- **Network simulation and virtualisation**: Students will engage with software for 5G network simulation, virtualised environments, and network slicing techniques to understand the structure and behaviour of next-generation network systems.
- **Data analytics and visualisation**: The course introduces platforms used for real-time network monitoring, predictive analytics, and data-driven decision-making within 5G ecosystems.
- **E-learning and collaborative ICT tools**: Throughout the course, students will engage with digital learning platforms and collaborative tools, supporting teamwork, communication, and a fully connected learning experience.

By acquiring and applying these digital competencies, students will be well-equipped to thrive in the evolving professional landscape of industrial IoT technologies.

Assessment and Feedback Mechanism

The assessment methods utilised in this course aim to evaluate students' knowledge, skills, and competencies in an integral and well-rounded manner. The assessment aligns with the learning results and allows students to demonstrate their expertise in the most significant areas of the course. The assessment methods include the following:

- **Multiple-Choice Questions (MCQs)** (30%) will be used to assess students' understanding of foundational principles related to IoT, Industry 4.0, and manufacturing. MCQs are designed to test recall and application of master principles.
- **Short Essays/Reports** (30%) will allow students to go in-depth about a specific topic, critically analysing current trends or challenges in Industrial IoT technologies and offering well-reasoned arguments based on evidence.
- **Case Studies** (20%) will enable students to work through and resolve actual case situations in OT and ICT integrated systems. Students will be expected to critically

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examine the case, suggest solutions, and support their reasoning with data and theoretical evidence.

- **Short Answer Questions** (20%) will allow students to display their ability to give brief answers and apply what they know to specific situations in industrial IoT applications.

The primary assessment methods emphasise scalability and automation, with MCQs and short essays/reports accounting for most grading weight. Case studies may be offered optionally for learners in instructor-supported contexts or as capstone activities.

The feedback mechanisms will be the following:

- MCQs will be provided with immediate feedback to help students identify correct and incorrect responses.
- Instructor feedback for written exercises (e.g., essays, reports) will be given as personalised comments about strengths and weaknesses.
- The instructor will also provide case study feedback, allowing students to refine their analysis and recommendations.

Recommended readings

The following readings are recommended to support learning in each module. These resources include foundational overviews, applied research, and state-of-the-art surveys relevant to Industrial IoT technologies. Where available, links to open-access versions or institutional library access will be provided through the course platform.

Module 1 readings:

Mark Weiser, The Computer for the 21st Century, Scientific American, September 1991.

Silvia Liberata Ullo and G. R. Sinha, Advances in Smart Environment Monitoring Systems Using IoT and Sensors, Sensors (Basel), vol. 20, no. 11, May 31, 2020, article 3113.

Alexander Gillis, What is internet of things (IoT)?, IOT Agenda. Available at: https://internetofthingsagenda.techtarget.com/definition/Internet-of-Things-IoT

Seraphin B. Calo et al., Edge computing architecture for applying AI to IoT, Proceedings of the 2017 IEEE International Conference on Big Data (Big Data), IEEE, 2017.

T. N. Gia, M. Ali, I. B. Dhaou, A. M. Rahmani, T. Westerlund, P. Liljeberg, H. Tenhunen, IoT-based continuous glucose monitoring system: A feasibility study, Procedia Computer Science, Volume 109, 2017

A. K. Teshome, B. Kibret, and D. TH Lai. A review of implant communication technology in WBAN: Progress and challenges, IEEE reviews in biomedical engineering 12 (2018): 88-99

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B. L.Stojkoska, K. V. Trivodaliev, A review of Internet of Things for smart home: Challenges and solutions, Journal of Cleaner Production, Volume 140, Part 3, 2017

Intel Solution Brief, Intel is building the future of retail, https://www.intel.co.jp/content/dam/www/public/us/en/documents/solution-briefs/rfid-sensor-platformbrief.pdf

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Jason Del Rey, Amazon's store of the future is delayed, Vox Recode, March 2017, https://www.vox.com/2017/3/27/15072084/amazons-go-future-store-delayed-opening

Cecilia Kang, Here Comes the Full Amazonification of Whole Foods, New York Times 2/2022, https://www.nytimes.com/2022/02/28/technology/whole-foods-amazon-automation.html

Ying Wang and Yu Hu, Design of Electronic Shelf Label Systems Based on ZigBee, 4th International Conf. on Software Engineering and Service Science. IEEE, 2013

M. S. Farooq et al. Role of IoT technology in agriculture: A systematic literature review, Electronics 9.2 (2020): 319

W.-L. Chen et al., AgriTalk: IoT for Precision Soil Farming of Turmeric Cultivation, IEEE Internet of Things Journal, vol. 6, no. 3, pp. 5209-5223, June 2019

L. Nóbrega, A. Tavares, A. Cardoso and P. Gonçalves, Animal monitoring based on IoT technologies, IoT Vertical and Topical Summit on Agriculture, 2018, pp. 1-5

S. Giordano, I. Seitanidis, M. Ojo, D. Adami and F. Vignoli, IoT solutions for crop protection against wild animal attacks, IEEE Intl. Conf. on Environmental Engineering, 2018

Adam Dunkels, Contiki – a lightweight and flexible operating system for tiny networked sensors, Proc. of the 29th Annual IEEE Intl. Conf. on Local Computer Networks., pp. 455–462

C. Gomez, J. Oller, J. Paradells, Overview and Evaluation of Bluetooth Low Energy: An Emerging Low-Power Wireless Technology, Sensors, 12 (9): 11734–11753, 2012

IKEA Trådfri hacking on github: https://github.com/basilfx/TRADFRI-Hacking

J. Wang, Zigbee light link and its applications, IEEE Wireless Communications, 20. 6-7, 2013

L. Frenzel, What's The Difference Between ZigBee And Z-Wave?, Electronic Design, March 29, 2012, https://www.electronicdesign.com/technologies/communications/article/21796052/whats-the-difference-between-zigbeeand-zwave

M. T. Abbas et al., *Energy-Saving Solutions for Cellular Internet of Things – A Survey*, IEEE Access, vol. 10, pp. 62073–62096, 2022.

M. T. Abbas et al., *Guidelines for an Energy Efficient Tuning of the NB-IoT Stack*, Proceedings of the 2020 IEEE 45th LCN Symposium on Emerging Topics in Networking (LCN Symposium), Sydney, Australia, 2020, pp. 60–69.

M. T. Abbas et al., *On the Energy-efficient Use of Discontinuous Reception and Release Assistance in NB-IoT*, Proceedings of the 2022 IEEE 8th World Forum on Internet of Things (WF-IoT), Yokohama, Japan, 2022, pp. 1–7.

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Mobile IoT in a 5G Future, GSMA White Paper, October 2024. Available at: https://www.gsma.com

5G RedCap White Paper: Is 5G RedCap the Right Fit for Your IoT Connectivity Needs?, Quectel.

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Improving Energy Efficiency for Mobile IoT, GSMA White Paper, March 2022. Available at: https://www.gsma.com

https://www.enterpriseintegrationpatterns.com/patterns/messaging/MessageBus.html

MQTT Version 5.0 Specification. Available at: https://mqtt.org/mqtt-specification/

Building Facebook Messenger. Facebook Engineering Blog, August 12, 2011. Available at: https://engineering.fb.com/2011/08/12/android/building-facebook-messenger/

George Orwell, Animal Farm, New York: The New American Library, 1946. ISBN: 978-1-4193-6524-9.

Teletraffic Engineering Handbook, ITU-T Study Group 2. (Note: Uses "GoS" instead of QoS.)

MQTT SYS Topics Wiki. Available at: https://github.com/mqtt/mqtt.org/wiki/SYS-Topics

HiveMQ Blog. How to Get Started with MQTT. Available at: https://www.hivemq.com/blog/how-to-get-started-with-mqtt/

The Eclipse Mosquitto Project. Available at: https://mosquitto.org

Mosquitto Manual Pages:

mosquitto_pub client: https://mosquitto.org/man/mosquitto_pub-1.html

mosquitto_sub client: https://mosquitto.org/man/mosquitto_sub-1.html

MQTT Packet Format Overview. Available at: http://www.steves-internet-guide.com/mqtt-protocol-messages-overview/

Build Your Own Minimal MQTT Broker. Hackaday, May 9, 2016. Available at: https://hackaday.com/2016/05/09/minimal-mqtt-building-a-broker/

MQTT-SN (Sensor Networks) Overview. Available at: http://www.steves-internet-guide.com/mqtt-sn/

ZeroMQ RFC: ZMTP/3.1 Transport Layer Specification. Available at: https://rfc.zeromq.org/spec/23/

Advanced Message Queuing Protocol (AMQP) Official Site. Available at: https://www.amqp.org

Clemens Vasters. From MQTT to AMQP and Back. Available at: https://vasters.com/blog/From-MQTT-to-AMQP-and-back/

Module 2 readings:

M. Alabadi, A. Habbal and X. Wei, "Industrial Internet of Things: Requirements, Architecture, Challenges, and Future Research Directions," in IEEE Access, vol. 10, pp. 66374-66400, 2022, doi: 10.1109/ACCESS.2022.3185049.

- https://ieeexplore.ieee.org/document/9802088

K. S. Awaisi, Q. Ye and S. Sampalli, "A Survey of Industrial AIoT: Opportunities, Challenges, and Directions," in IEEE Access, vol. 12, pp. 96946-96996, 2024, doi: 10.1109/ACCESS.2024.3426279.

- https://ieeexplore.ieee.org/abstract/document/10591982

Module 3 readings:

Yin, C., Xiong, Z., Chen, H. et al. A literature survey on smart cities. Sci. China Inf. Sci. 58, 1–18 (2015).

- https://doi.org/10.1007/s11432-015-5397-4

Cai, M., Decaminada, T., Li, Y. et al. Linking smart cities and SDGs through descriptive analysis of US municipalities. Nat Cities 2, 144–148 (2025).

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Khashoggi, A.N., Mohammed, M.F.M. (2025). Smart Communities in Smart Cities: Investigating and Exploring Smart Cities' Social Attributes. In: Berkouk, D., Chatterjee, U., Bouzir, T.A.K., Dhaou, I.B. (eds) Proceedings of the 1st International Conference on Creativity, Technology, and Sustainability. CCTS 2024. Proceedings in Technology Transfer. Springer, Singapore.

- https://doi.org/10.1007/978-981-97-8588-9_46

Development of Soft Skills

The course integrates soft skills development through:

- **Verbal presentations** where students present complex technical concepts related to IoT, Industry 4.0, and manufacturing, fostering public speaking and the ability to articulate technical issues to non-technical individuals.
- **Problem-solving exercises** via case studies, debugging, and hands-on network simulations to develop critical thinking, adaptability, and decision-making.
- **Peer review activities** through which students critique each other's work in group projects, developing constructive criticism and analytical thinking abilities.

These soft skills are not assessed independently but are integrated into collaborative activities and instructor feedback processes, contributing to a holistic learning experience.

Industry Collaboration and Internships

Telecom and technology collaborations provide rich learning opportunities from the industry and practical exposure. Where institutional partnerships and resources allow, students are encouraged to engage in the following:

- **Industry guest lectures** by industry experts provide perspectives on future-looking 5G technologies for Industrial environments.
- **Problem-based learning** and business partner case studies expose the learners to real-world experiences, industry insights, and current solutions, thereby eliminating the learning experience gap that occurs for certain theoretical topics.
- **Industrial collaboration and workplace learning** experiences allow students to put their IoT expertise into practice in industrial environments, using it to apply to occupation-specific duties such as private 5G network data analysis and telecommunication infrastructures that integrate the cloud to manufacturing/smart city processes. Emphasis will be given to practical entrepreneurial activities or market-oriented exercises, including start-up case studies or market validation tasks.
- **Networking and mentorship** with other professionals in the profession augment career growth and foster industry relationships.

These collaborative opportunities are not guaranteed and depend on the specific institutional and regional context. They are offered when feasible and aim to enhance learner engagement with applied, occupation-specific experiences in the digital sector.

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Accessibility and Inclusivity

The course is designed to be inclusive and accessible to all learners, ensuring equal opportunities for participation and success.

- **Transcripts and subtitles** for video content provide accessibility for learners with hearing impairments and support those who prefer text-based learning.
- Language support for non-native speakers, including **glossaries** of technical terms and AI-powered translation tools, facilitates comprehension for diverse learners.
- **Flexible assessment formats**, such as oral presentations, written reports, and practical demonstrations, accommodate different learning preferences and needs.
- Customizable learning pace and materials, including **downloadable content** and asynchronous learning options, allow students to engage with the material at their own speed.
- Dedicated support for learners with disabilities, such as **extended assessment time** and **alternative task formats**, ensures an equitable learning experience.

These strategies reflect principles of Universal Design for Learning (UDL), promoting access and engagement for all learners regardless of background or ability.

ECVET/ECTS Credit Allocation

The total course is allocated 2 ECTS, distributed across modules as follows:

- Module 1: 0.66 ECTS (20 hours)
- Module 2: 0.66 ECTS (20 hours)
- Module 3: 0.66 ECTS (20 hours)

Abbreviation	Full Form
5G	Fifth Generation (Mobile Networks)
6G	Sixth Generation (Mobile Networks - Future)
AI	Artificial Intelligence
API	Application Programming Interface
eMBB	Enhanced Mobile Broadband
EU	European Union
ICT	Information and Communication Technologies
IoT	Internet of Things

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ITU	International Telecommunication Union
KSA	Knowledge, Skills, and Abilities
MCQ	Multiple Choice Question
MIMO	Multiple Input Multiple Output
mMTC	Massive Machine-Type Communications
NFV	Network Functions Virtualization
NR	New Radio
RAN	Radio Access Network
URLLC	Ultra-Reliable Low Latency Communication
ns2	Network Simulator 2

Table 33. List of Abbreviations for the course 'IoT, Industry 4.0, and Smart Cities'

4. Energy Efficiency and Sustainability in Advanced 5G Technologies

General Information

Course Title	Energy Efficiency and Sustainability in Advanced 5G Technologies
Learning Outcomes	• Understand the energy consumption patterns in 5G networks. • Apply energy efficiency techniques and sustainable network design principles. • Recognise the role of renewable energy integration and green networking strategies.
EQF Level	6
ECVET/ECTS Credits	2 ECTS
Total Learning Hours	60 hours (This aligns with the ECTS standard workload assumption of 25–30 hours per credit) Structure: • 20 hours of lectures, • 15 hours of practical exercises, • 25 hours of independent study

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Audience	Targeted at engineering students, telecom professionals, and sustainability specialists involved in 5G deployment
Prerequisites	• Basic understanding of digital communication systems • Familiarity with concepts of sustainability or environmental science • Interest in the intersection of technology and green innovation
Language of Instruction	English
Coordinator	Gintautas Dervinis (TECHIN)

Table 34. General info for the course 'Energy Efficiency and Sustainability in Advanced 5G Technologies'

Note about the Total Learning Hours and Required Effort

The **20 hours of lectures** are delivered through a mix of **concise, pre-recorded videos**, **interactive presentations**, and **expert-led content** that target core knowledge areas in **sustainability** and **5G technology**. Each lecture session is designed to focus on specific **learning outcomes** and is supplemented with **brief comprehension tasks** to reinforce learning without exceeding the time budget.

The **15 hours of practical exercises** include **applied simulations**, **design activities**, **case-based analysis**, and **collaborative group work** conducted online. These activities are carefully calibrated in **complexity and scope** to remain within the allocated time while enabling **skill development** and **practical engagement** with energy efficiency strategies in telecom networks. The **depth of both content and exercises** is intentionally adjusted to reflect the total course hours, ensuring that learners are not overburdened and that expectations remain aligned with the 2 ECTS credit allocation.

The **independent study component** is tentatively distributed as follows:

- **12 hours** for reading, video-based learning, and topic review
- **3 hours** for completing **quizzes and MCQs** through the LMS
- **6 hours** to prepare and submit a **final assignment** (written or recorded)
- **4 hours** dedicated to **self-evaluation** using a structured checklist aligned with the course learning outcomes, encouraging students to reflect on their knowledge and skills before completing the course

The time allocated for **MCQs and quizzes** is considered part of the **independent study workload**, as these tasks are completed individually through the Learning Management System (**LMS**), without the need for instructor-led facilitation. They are designed as **self-paced knowledge checks** that support **formative learning** and help students reinforce their understanding of key concepts between lectures and practical sessions. This distinction ensures that the independent learning hours are fully utilised while maintaining a **manageable grading load**.

In contrast, the **practical exercises** represent **structured, instructor-guided** learning experiences that require deeper engagement. These activities include working with **energy efficiency simulations**, applying **design tools** to network optimisation scenarios, analysing real-world **sustainability case studies**, and participating in **collaborative planning tasks**. These exercises are aligned with the **skill-building objectives** of the course and are deliberately scoped to ensure **meaningful outcomes within the allocated time**.

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This **balanced design** across lectures, exercises, and self-directed study ensures that the total workload remains **realistic, meaningful, and achievable** within the **60-hour frame** defined by the **2 ECTS credit allocation**.

To further support ECTS alignment, the table below maps each major course activity to its estimated time allocation and the targeted levels of cognitive complexity, following **Bloom's Taxonomy**. This ensures that the overall 60-hour effort corresponds not only to quantity, but also to appropriate depth and progression of learning.

Learning Component	Hours	Bloom's Level(s) Targeted
Lectures	20	**Remember**, **Understand**
Practical Exercises	15	**Apply**, **Analyse**
Quizzes & MCQs	3	**Understand**, **Apply**
Final Assignment	6	**Analyse**, **Evaluate**, **Create**
Reading & Topic Review	12	**Understand**, **Apply**
Self-Evaluation Checklist	4	**Evaluate**, **Reflect** (metacognition)
Total	**60**	–

Table 35. Mapping of Learning component, dedicated hours, and Bloom's level for the course 'Energy Efficiency and Sustainability in Advanced 5G Technologies'

Course Description

This course is part of the 5G-DiGITs curriculum and aims to provide comprehensive knowledge, skills, and abilities (KSAs) in advanced 5G technologies, focusing on sustainability and energy efficiency. The curriculum aligns with Erasmus+ requirements and the KSA methodology. It covers technical skills, sustainability practices, and industry-relevant competencies for 5G professionals.

During the course, students will be introduced to and able to explain the principles of **energy consumption** management, relevant regulations, and the application of **energy efficiency techniques in 5G networks**. Discussing **emerging trends in sustainable 5G development**, the course will provide the basics of **sustainable network development** and **renewable energy integration in 5G network** tactics that will help implement **green networking strategies** and provide a deeper understanding of the importance of **smart grids and energy-aware networking**.

The course is structured around four thematic modules:

- **Module 1:** Fundamentals of Energy Consumption in 5G Network
- **Module 2:** Energy Efficiency Techniques and Network Optimisation
- **Module 3:** Renewable and Hybrid Energy Integration in 5G
- **Module 4:** Regulatory, Policy, and Market Perspectives

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After completing the course, students will be able to **analyse 5G energy consumption data**, **implement energy efficiency measures in networks**, **evaluate renewable energy solutions for 5G**, **develop sustainability reports for telecom networks**, optimise **energy usage in real-world 5G deployments**, as well as **conduct energy audits for 5G operators.**

Detailed Learning objectives (instructor-oriented)

The following learning objectives are defined from an instructional perspective, providing pedagogical guidance for the delivery of each module.

Module	Learning Objectives
Module 1 **Fundamentals of Energy Consumption in 5G Network**	• Introduce the structural and functional elements of 5G networks that drive energy consumption • Facilitate understanding of the environmental lifecycle impact of telecom infrastructure • Develop learners' capacity to interpret energy usage data within a 5G system context • Connect smart grid integration and energy-aware network design with real-world case studies
Module 2 **Energy Efficiency Techniques and Network Optimization**	• Teach core techniques for reducing power consumption in 5G networks, including sleep modes and dynamic scheduling • Explain architectural approaches for sustainable 5G network design • Enable application of AI/automation for real-time energy optimisation • Guide critical comparison of conventional and energy-efficient network strategies
Module 3 **Renewable and Hybrid Energy Integration in 5G**	• Introduce the technical and operational aspects of integrating solar, wind, and hybrid systems in telecom deployments • Guide learners through feasibility analysis exercises for renewable-powered 5G scenarios in diverse geographies • Present cutting-edge innovations in sustainable energy for telecom infrastructure • Encourage evaluation of trade-offs and system-level planning in hybrid energy systems
Module 4 **Regulatory, Policy, and Market Perspectives**	• Provide an overview of regional and global sustainability policies relevant to the telecom sector • Develop learners' ability to interpret ESG and reporting frameworks (e.g., GRI, ITU standards) • Introduce methodologies for conducting energy audits in compliance with telecom regulations

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	• Explore business case studies that illustrate how policy can enable or constrain sustainable 5G deployment
Cross-cutting Abilities (Soft Competencies)	• Collaborate effectively across disciplines to co-develop energy-efficient and sustainable 5G solutions • Communicate technical sustainability strategies clearly through reports, presentations, and policy briefs. • Critically reflect on the societal and ecological impacts of energy consumption in telecom systems • Demonstrate initiative and entrepreneurial thinking in proposing innovative, low-carbon 5G deployments

Table 36. Learning objectives for the course 'Energy Efficiency and Sustainability in Advanced 5G Technologies'

Detailed Learning Outcomes (student-oriented)

By the end of this course, students will be able to (all learning outcomes are numbered so that they can easily be identified or linked during course planning and implementation):

Module	Learning Outcomes
Module 1 **Fundamentals of Energy Consumption in 5G Network**	Enable students to: 1. Identify the main components and processes contributing to energy consumption in 5G networks 2. Describe the environmental impact of 5G systems throughout their lifecycle 3. Understand the relationship between 5G networks and smart energy systems • Interpret energy usage patterns and sustainability challenges in network deployment
Module 2 **Energy Efficiency Techniques and Network Optimization**	Enable students to: 4. Explain strategies and architectures that enhance energy efficiency in 5G 5. Apply energy-aware techniques such as dynamic sleep modes or adaptive routing 6. Recognise the role of AI and automation in energy-efficient network management Compare traditional and sustainable design approaches in telecom networks
Module 3	Enable students to: 7. Understand the integration of solar, wind, and hybrid power sources in telecom systems

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Renewable and Hybrid Energy Integration in 5G	8. Evaluate the feasibility of renewable-powered 5G deployments in various environments 9. Analyse case studies of sustainable telecom infrastructure initiatives Identify technical and environmental trade-offs in green energy integration
Module 4 **Regulatory, Policy, and Market Perspectives**	Enable students to: 10. Understand global and regional policies driving energy efficiency in telecom 11. Interpret key sustainability standards and reporting frameworks in the ICT sector 12. Discuss the impact of regulation on network design and operations Explore the role of policy in accelerating green transitions in telecom markets

Table 37. Learning outcomes for the course 'Energy Efficiency and Sustainability in Advanced 5G Technologies'

Note: Comment on differentiation between this course vs. 'Green Skills' course: *There is some* ***intentional thematic overlap*** *with it (e.g., sustainability, carbon footprint, lifecycle thinking), but the* ***focus here is more technical and operational****. Example of clear differentiation:*

- ***Green Skills*** *→ broader eco-design, circular economy, and policy analysis.*
- ***Energy Efficiency and Sustainability*** *→ concrete actions within 5G systems: audits, real-time energy analysis, renewable integration, smart grids.*

The alignment between modules and KSA items is presented in the table below.

Module	Knowledge (General Competencies)	Skills (Specific Competencies)	Abilities (Soft Competencies)
Module 1 **Fundamentals of Energy Consumption in 5G Network**	**Energy consumption in 5G networks**: Covers how 5G systems use energy across components and operational layers. **Environmental impact of 5G technologies**: Addresses the broader ecological effects of 5G deployment, including emissions and lifecycle considerations. **Smart grids and energy-aware networking**: Explores the link	**Analyse 5G energy consumption data**: Involves using monitoring tools to assess how power is distributed across network components	**Optimize energy-aware 5G deployments:** Apply sustainable design principles to reduce energy use during network rollout and operation

	between 5G networks and intelligent energy management systems.		
Module 2 **Energy Efficiency Techniques and Network Optimization**	**Energy efficiency techniques in 5G**: Examines strategies to reduce energy usage in mobile networks. **Sustainable network design**: Introduces principles for building telecom systems with reduced environmental impact. **Green networking strategies:** Focuses on approaches like load balancing and sleep modes for energy savings.	**Implement energy efficiency measures in networks**: Apply optimisation techniques such as sleep modes or adaptive resource allocation in 5G. **Optimise energy usage in real-world 5G deployments**: Focuses on identifying inefficiencies and tuning performance in existing network setups.	**Integrate sustainability into 5G project planning**: Encourages the inclusion of environmental criteria when designing and managing 5G systems.
Module 3 **Renewable and Hybrid Energy Integration in 5G**	**Renewable energy integration in 5G networks**: Discusses how solar, wind, and hybrid sources can be used to power telecom infrastructure. **Emerging trends in sustainable 5G development**: Highlights recent innovations in low-impact and eco-friendly network technologies.	**Evaluate renewable energy solutions for 5G**: Includes assessing the technical and economic feasibility of solar, wind, or hybrid energy options for powering 5G	**Collaborate across disciplines for sustainable telecom innovation**: Involves working with diverse teams to co-create greener telecom solutions. **Demonstrate initiative in developing low-impact energy solutions**: Promotes active contribution to the design of renewable-powered or hybrid telecom systems.
Module 4 **Regulatory, Policy, and Market Perspectives**	**Policy and regulatory framework for energy-efficient 5G**: Reviews global and regional policies that guide sustainable 5G deployment and	**Develop sustainability reports for telecom networks**: Entails creating documentation	**Advocate for green telecom policies**: Supports engagement in shaping and promoting regulatory frameworks that

	telecom energy governance.	such as lifecycle analyses and performance summaries to support reporting. **Conduct energy audits for 5G operators**: Covers how to measure and evaluate total energy demand and usage in line with regulatory expectations	advance sustainability in telecom

Table 38. Alignment between KSA items and modules for the course 'Energy Efficiency and Sustainability in Advanced 5G Technologies'

Detailed Modules and Units

MODULE	**Module 1**: Fundamentals of Energy Consumption in 5G Network
UNIT	**Unit 1.1: Introduction to Energy Flows in 5G**
Learning Hours	7 hours
Learning Outcomes	By the end of this unit, students will be able to: • Identify key components and functions of 5G networks contributing to energy demand • Describe typical energy distribution patterns in 5G infrastructure • Recognise the main energy hotspots in mobile and fixed access networks • Compare energy usage across different generations of mobile networks
Teaching methods	Video lectures, interactive reading materials, and data interpretation exercises
Assessment methods	Included in the **module-level quiz** (formative, auto-graded). Brief written reflections are integrated into reading tasks; no separate submission.
Prerequisites	None
UNIT	**Unit 1.2: Environmental Impact of Telecom Infrastructure**
Learning Hours	8 hours

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Learning Outcomes	By the end of this unit, students will be able to: • Analyse the environmental footprint of 5G deployments using lifecycle thinking • Discuss the long-term sustainability challenges of scaling telecom infrastructure • Evaluate carbon emissions and energy sourcing in telecom operations • Understand the link between energy consumption and environmental degradation
Teaching methods	Pre-recorded content, case studies, and guided reading
Assessment methods	The short essay task supports the final assignment and may be reused or adapted. Worksheet elements are covered in guided reading activities.
Prerequisites	Unit 1.1

Table 39. Module 1 for the course 'Energy Efficiency and Sustainability in Advanced 5G Technologies'

MODULE	**Module 2**: Energy Efficiency Techniques and Network Optimisation
UNIT	**Unit 2.1: Strategies for Network Energy Efficiency**
Learning Hours	9 hours
Learning Outcomes	By the end of this unit, students will be able to: • Describe common methods to improve energy performance in 5G systems • Understand how resource management and energy-aware routing reduce waste • Evaluate trade-offs in implementing sleep modes or load balancing • Compare energy efficiency gains from AI-based versus static strategies
Teaching methods	Video lectures, simulations, performance walkthroughs
Assessment methods	Covered in the **module-level quiz**. Strategy assignment feeds into the **final project deliverable**; no separate submission required.
Prerequisites	None
UNIT	**Unit 2.2: Designing Sustainable Network Architectures**

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Learning Hours	6 hours
Learning Outcomes	By the end of this unit, students will be able to: • Apply sustainability principles in planning 5G network topologies • Identify features of sustainable backhaul, fronthaul, and RAN design • Assess infrastructure upgrades based on environmental and energy criteria • Explore emerging architectural models that prioritise energy efficiency
Teaching methods	Design tutorials, annotated diagrams, case-based readings
Assessment methods	Activities support the **final assignment**; students may draw on design proposal work, but will not submit a separate case analysis.
Prerequisites	Unit 2.1

Table 40. Module 2 for the course 'Energy Efficiency and Sustainability in Advanced 5G Technologies'

MODULE	Module 3: Renewable and Hybrid Energy Integration in 5G
UNIT	**Unit 3.1: Renewable Energy Systems in Telecom**
Learning Hours	8 hours
Learning Outcomes	By the end of this unit, students will be able to: • Explain how solar, wind, and hybrid systems can power telecom networks • Assess the suitability of renewable sources based on deployment context • Analyse energy generation potential for different site configurations • Identify limitations and challenges in scaling renewables for 5G
Teaching methods	Video lectures, renewable system demos, self-guided analysis
Assessment methods	Included in the **module-level quiz**. Key findings from the system applicability report are expected to inform the **final assignment**, which will not be submitted separately.
Prerequisites	None
UNIT	**Unit 3.2: Design of Green 5G Deployment Scenarios**
Learning Hours	7 hours

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Learning Outcomes	By the end of this unit, students will be able to: • Integrate renewable energy models into 5G rollout planning • Propose sustainable power solutions for rural or off-grid sites • Estimate the cost-benefit and carbon impact of green deployment strategies • Simulate hybrid energy scenarios using basic tools or case data
Teaching methods	Case studies, planning templates, and example-based simulations
Assessment methods	This unit contributes directly to the **final deliverable**, which is structured as a **real-world simulation** (e.g., a green deployment plan or sustainability audit for a hypothetical telecom operator). The activity mirrors professional tasks and constraints found in network planning or sustainability consulting. **Peer feedback** may be conducted informally and incorporated into the self-evaluation process.
Prerequisites	Unit 3.1

Table 41. Module 3 for the course 'Energy Efficiency and Sustainability in Advanced 5G Technologies'

MODULE	Module 4: Regulatory, Policy, and Market Perspectives
UNIT	**Unit 4.1: Regulatory Frameworks and Compliance**
Learning Hours	8 hours
Learning Outcomes	By the end of this unit, students will be able to: • Identify global and regional sustainability regulations affecting 5G • Interpret telecom policy documents related to energy performance • Analyse compliance strategies in network operations and design • Understand how regulatory bodies monitor energy efficiency in ICT
Teaching methods	Video content, guided document analysis, and policy overview readings
Assessment methods	Quiz content is included in the **module-level quiz**. Policy brief concepts may feed into the **final report or presentation**, but are not separately submitted.
Prerequisites	None
UNIT	**Unit 4.2: Business Models and Policy Innovation**
Learning Hours	7 hours

Learning Outcomes	By the end of this unit, students will be able to: • Discuss how sustainability influences business strategy in telecom • Propose policy recommendations to incentivise green network investments • Reflect on ethical and governance challenges in the digital-green transition • Evaluate existing green business models within the ICT sector
Teaching methods	Case-based examples, business model templates, and guided articles
Assessment methods	Reflection and analysis are embedded within the **final deliverable**, which may simulate a **business or policy recommendation scenario** for a telecom operator or regulator. This approach ensures alignment with **real working conditions** and exposes learners to professional-level decision-making processes. No standalone submission is required.
Prerequisites	Unit 4.1

Table 42. Module 4 for the course 'Energy Efficiency and Sustainability in Advanced 5G Technologies'

Learning and Teaching Methods

The course will adopt diverse teaching methods aligned with the KSA framework and tailored to the technical and sustainability-oriented focus of each module:

- **Lectures** will introduce core concepts such as energy consumption patterns, sustainable design principles, and regulatory frameworks in 5G networks.
- **Case studies** will be used to explore real-world implementations of energy-efficient 5G systems, renewable-powered telecom infrastructure, and policy-driven sustainability models.
- **Interactive simulations and tools** will allow students to model energy consumption scenarios, apply optimisation algorithms, and assess the impact of renewable integration in 5G deployments.
- **Collaborative group work** will support the development of transversal skills by engaging students in team-based projects on green network planning or sustainability audits.
- **Problem-based learning (PBL)** will be embedded in practical exercises where learners solve complex challenges related to 5G network efficiency, carbon reduction, and hybrid energy sourcing.
- **Blended and online delivery formats** will be supported via digital learning platforms, enabling flexible access to course content, remote lab activities, and peer collaboration across institutions.

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Work-Based Learning

The assessment strategy for this course is designed to evaluate learners' mastery of the intended knowledge, skills, and abilities in a fully online environment. Various formative and summative methods will be implemented through the Moodle Learning Management System (LMS), allowing for flexible, accessible, and interactive assessment experiences.

- **Online quizzes and MCQs** will be integrated into the LMS to assess foundational understanding of energy consumption patterns, smart grids, sustainability principles, and regulatory frameworks. These will be automatically graded and provide immediate feedback to support continuous learning, particularly during Modules 1 and 4.
- **Short reflective essays and written assignments** will be submitted through Moodle's assignment tool. These tasks will evaluate students' ability to critically analyse environmental trade-offs, policy implications, and technical challenges in green 5G deployment. Instructors will provide personalised, rubric-based feedback directly within the platform.
- **Project-based technical reports** will be used to assess applied skills in energy optimisation, renewable energy integration, and network sustainability planning (Modules 2 and 3). Students will upload structured documents (e.g., energy audit summaries, LCA evaluations, or deployment proposals) and may also be asked to incorporate graphs or simulation screenshots as evidence.
- **Oral presentations and video pitches** will be delivered asynchronously or synchronously using Moodle's integrated tools (e.g., BigBlueButton or recorded submissions). These will assess communication skills, systems thinking, and the ability to explain technical solutions to mixed audiences.
- **Group work and collaborative assignments** will be supported through Moodle forums, wikis, or shared cloud documents. These activities will assess teamwork, innovation, and collaborative problem-solving in tasks such as green telecom system design or scenario-based planning.
- **Peer assessment and self-reflection** activities will be embedded into the course to foster metacognition and transversal skills. Using Moodle's workshop module or survey tools, students will review peers' work against shared criteria and reflect on their individual progress and contributions.

Assessment methods will be distributed across the course timeline and aligned with each module's specific outcomes, ensuring a holistic and competency-based evaluation process. Feedback mechanisms will be used regularly to promote learner engagement, motivation, and self-improvement.

Digital Competencies

This course develops digital competencies in line with the **European Digital Competence Framework for Citizens (DigComp[1])**, with a strong focus on technical application in sustainable telecommunications and energy-aware network management.

Learners will strengthen their abilities across the following DigComp competence areas:

- **Information and Data Literacy (DigComp Area 1)**: Students will learn to access, analyse, and interpret energy consumption and sustainability-related data from 5G systems. This

[1] EU Science Hub, Digital Competence Framework for Citizens (DigComp)

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includes using dashboards, lifecycle tools, and performance analytics to support decision-making.

- **Digital Communication and Collaboration (Area 2)**: Through Moodle-based group work, forums, and collaborative planning exercises, students will co-design energy optimisation strategies and contribute to peer reviews and joint deliverables.
- **Digital Content Creation (Area 3)**: Students will produce technical reports, visualisations, and presentations demonstrating their ability to document and communicate complex sustainability solutions in telecom infrastructure.
- **Digital Safety and Data Awareness (Area 4)**: Learners will understand the importance of protecting operational data and respecting privacy when working with energy monitoring platforms, remote infrastructure tools, and sustainability metrics. The focus is on responsible and ethical use of digital systems in green telecom contexts, not network-level cybersecurity.
- **Problem-Solving and Innovation (Area 5)**: Learners will use digital tools to simulate energy scenarios, evaluate alternative network configurations, and develop optimisation models, strengthening their ability to apply digital skills in sustainability-focused innovation.

While this course shares core digital learning infrastructure with the other 5G-DiGITs modules, its DigComp application focuses on the **technical, data-centric, and problem-solving dimensions of digital competence** related to **energy efficiency and green telecom engineering**.

Assessment and Feedback Mechanism

This course's assessment and feedback strategy is designed to ensure transparent, timely, and competency-based evaluation, adapted to the fully online delivery model through Moodle. It reflects the need for technical accuracy and reflective, sustainability-oriented thinking in energy-aware 5G network design.

Assessment mechanisms include:

- **Modular, outcome-aligned evaluation**, with clear rubrics for each task, tied to the KSA structure and linked to specific learning outcomes.
- **Embedded formative assessments** (e.g., interactive quizzes, self-assessment prompts) to provide students with real-time feedback and allow instructors to monitor learning progress.
- **Summative evaluations** such as project reports, simulation outputs, and presentations, graded via rubrics and accompanied by qualitative instructor feedback through Moodle's feedback tools.

To ensure a balanced and realistic workload for a 2 ECTS course, the number of formal assessments has been streamlined. **Module-level quizzes** have replaced per-unit quizzes and are designed as **low-stakes, formative activities**, automatically graded within the LMS. These support ongoing learning without adding instructor burden.
Additionally, a **single main summative deliverable** — either a technical report or a recorded presentation — has been designated as the final output. This assessment strategy maintains learner engagement while aligning with the total 60-hour workload.

Each assessment component has been designed with the course workload in mind. Estimated completion times are as follows: **module-level quizzes: ~30–45 minutes each**; **final assignment: ~6 hours total**, including research, drafting, and submission.

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Feedback is delivered:

- **Individually**, through annotated submissions, LMS-based messaging, and asynchronous video feedback.
- **Collectively**, through discussion forums and automated summaries, to highlight common strengths and areas for improvement.
- **Peer-to-peer**, especially within group projects, using structured peer review forms integrated into the platform.

Continuous feedback loops support academic performance and foster learner agency and reflection, particularly in the design of sustainable telecom systems under real-world constraints.

The final deliverable may tentatively take the form of a **capstone simulation**, such as preparing a **sustainability audit plan** or **deployment proposal** for a hypothetical 5G operator. This assignment is designed to mirror real-world roles and tasks encountered in telecom or energy strategy roles. Where possible, case data will be drawn from **industry scenarios or representative datasets** to enhance practical relevance and transferability.

Recommended readings

The following readings are recommended to support learning in each module. These resources include foundational overviews, applied research, and state-of-the-art surveys relevant to Beyond 5G (B5G) technologies. The course platform will provide links to open-access versions or institutional library access where available.

Module 1: Fundamentals of Energy Consumption in 5G Network

- **“Energy Efficiency for 5G and Beyond 5G: Potential, Limitations, and Future Directions”**

Sensors 2024, 24(22), 7402

This article presents an exhaustive review of power-saving research conducted for 5G and beyond 5G networks in recent years, elucidating the advantages, disadvantages, and key characteristics of each technique.

https://www.mdpi.com/1424-8220/24/22/7402

- **“5G Energy Efficiency Overview”**

Shurdi O., Ruci L., Biberaj A. & Mesi G. (2021). 5G Energy Efficiency Overview. *European Scientific Journal*, 2021, ESJ, 17(3), 315.

This article brings a general overview of smartphones power consumption issues on implementations of currently new 5G technologies.

https://www.researchgate.net/publication/349136327_5G_Energy_Efficiency_Overview

Module 2: Energy Efficiency Techniques and Network Optimization

- **“Energy Efficiency Concerns and Trends in Future 5G Network Infrastructures”**

Energies 2021, 14, 5392.

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This article describes 5G's capabilities to achieve lower power consumption and, most importantly, dynamic adaption of the network elements to any sort of energy

requirements, to ensure effective functioning.

https://www.researchgate.net/publication/354227117_Energy_Efficiency_Concerns_and_Trends_in_Future_5G_Network_Infrastructures

- **"A Comprehensive Overview of Network Slicing for Improving the Energy Efficiency of Fifth-Generation Networks"**

Sensors 2024, 24(10), 3242

This article analyses 5G network slicing and the energy demand of different network slicing use cases and mobile virtual network operator realisations based on network slicing. The paper also overviews standardised key performance indicators for assessing 5G network slices' energy efficiency and discusses energy efficiency in 5G network slicing lifecycle management.

https://www.mdpi.com/1424-8220/24/10/3242

Module 3: Renewable and Hybrid Energy Integration in 5G

- **"5G Wireless Networks in the Future Renewable Energy Systems"**

Frontiers in Energy Research, Sec. Smart Grids, Volume 9 – 2021

This article focuses on the strategies that employ the fifth generation (5G) wireless networks in the optimal management of demand-side response in the future energy systems with the high penetration of renewable energy sources (RES). It also compares the advantages and challenges of 5G networks in demand-response renewable energy grids.

https://www.frontiersin.org/journals/energy-research/articles/10.3389/fenrg.2021.714803/full

- **"A Survey on Green Enablers: A Study on the Energy Efficiency of AI-Based 5G Networks"**

Sensors (Basel), 2024, 24(14), 4609

The primary objective of this survey is to analyse AI's integration into 5G networks for enhanced energy efficiency. By exploring this intersection between AI and 5G, this survey aims to identify potential strategies and techniques for optimizing energy consumption while maintaining the desired network performance and user experience.

https://pmc.ncbi.nlm.nih.gov/articles/PMC11281033/

Module 4: Regulatory, Policy, and Market Perspectives

- **"5G and Government: A Regulatory Roadmap"**
  Wiley Rein LLP, 2024.
  This comprehensive guide examines the regulatory landscape of 5G deployment, discussing policy considerations, compliance challenges, and the role of government in facilitating sustainable 5G infrastructure.
  https://www.wiley.law/media/handbook/550_2021-Wiley-5G-Roadmap.pdf

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- **"Regulation and Innovation in 5G Markets"**
  Telecommunications Policy, 2021.
  This article analyses how different regulatory approaches impact innovation in 5G markets, emphasising the balance between regulation and promoting sustainable technological advancements.
  https://www.sciencedirect.com/science/article/pii/S0308596121001646

- **"5G and Human Rights: What's the Connection?"**
  Ericsson Blog, 2021.
  This piece explores the ethical considerations of 5G technology, discussing potential human rights implications and the importance of responsible deployment to ensure equitable access and privacy.
  https://www.ericsson.com/en/blog/2021/3/5g-human-rights

- **"Green is Good for Business: Embedding Sustainability in Digital Transformation"**
  Huawei, 2023.
  This white paper discusses how businesses can integrate sustainability into their digital transformation strategies, highlighting the role of 5G in achieving environmental goals and the associated regulatory considerations.
  https://carrier.huawei.com/~/media/cnbgv2/download/better-world/telco-sustainability-whitepaper.pdf

- **"5G Regulatory Policy and Assignment Strategies"**
  Coleago Consulting, 2023.
  This document provides insights into regulatory policies and spectrum assignment strategies for 5G, focusing on creating an environment that encourages investment while addressing sustainability concerns.
  https://www.coleago.com/app/uploads/2018/03/5G-Regulatory-Policy-and-Assignment-Strategies.pdf

Development of Soft Skills

In line with the KSA framework and Erasmus+ transversal goals, this course intentionally integrates soft skills development throughout the learning experience. Students will practice these competencies in realistic, sustainability-focused telecom scenarios and team-based technical challenges.

Key soft skills cultivated in this course include:

- **Collaboration**: Learners will engage in group projects where they must integrate knowledge from telecom engineering, environmental science, and policy domains to propose sustainable 5G solutions.
- **Communication**: Students will develop the ability to present energy efficiency strategies and sustainability reports to varied audiences using technical evidence and persuasive storytelling.
- **Critical Thinking and Systems Analysis**: Assignments require learners to evaluate trade-offs, justify design decisions, and reflect on the long-term impacts of telecom deployments on the environment.

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- **Initiative and Innovation**: Through open-ended tasks, students will propose new configurations, tools, or methods for reducing energy use in 5G systems, encouraging entrepreneurial thinking within technical constraints.

These soft skills are integrated into individual and collaborative tasks and evaluated through formative feedback, peer review, and reflection components built into the course.

Industry Collaboration and Internships

While this course is implemented primarily by an academic institution and a specialised SME, it is designed with firm reference to current trends and practices in the telecommunications and sustainable energy sectors. Industry relevance is embedded through case materials, scenario-based tasks, and alignment with professional competencies required in the evolving 5G ecosystem.

Learners will be exposed to real-world insights and indirect industry collaboration through:

- **Case-based learning**: Course content incorporates case studies and reports from public and industry sources (e.g., telecom providers, green network initiatives, energy efficiency standards) to contextualise technical and sustainability challenges.
- **Scenario-driven projects**: Learners will complete mini-projects simulating consultancy or technical roles within green telecom initiatives — such as designing energy optimisation plans or evaluating renewable integration strategies.
- **Guest insights (where available)**: Optional contributions from professionals working in 5G, green ICT, or energy management may be included to enhance practical understanding, depending on availability and partnerships.
- **Career and industry orientation**: The course provides exposure to the types of roles, challenges, and technical expertise currently in demand in the telecom and green energy sectors, preparing learners for internships or career paths in these fields.

While formal internships are not embedded within the course, students will gain skills applicable to professional environments in telecom sustainability, energy systems optimisation, and digital infrastructure planning.

Accessibility and Inclusivity

This course is designed to be fully accessible and inclusive, in alignment with the principles of the Erasmus+ programme and the European Pillar of Social Rights. All teaching materials and activities are delivered via a Moodle-based learning platform, ensuring flexibility in terms of time, location, and learning pace.

Specific measures include:

- **Accessible digital content**, including captioned videos, screen-reader-friendly documents (PDF/HTML formats), and alt-text for images and graphs in technical visualisations.
- **Inclusive instructional design**, allowing for multiple forms of engagement and assessment (e.g., written reports, recorded presentations, group and solo tasks), to accommodate different learning preferences and abilities.
- **Barrier-free participation**, with no physical classroom requirements, enabling access for geographically remote or mobility-constrained learners.

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- **Cultural and linguistic neutrality**, with content and examples designed to avoid bias and be understandable to learners from different EU backgrounds and professional profiles.

In the context of this course on *Energy Efficiency and Sustainability in Advanced 5G Technologies*, accessibility also means ensuring that technical tools (e.g., simulators, energy dashboards) are introduced with clear guidance and alternative materials when needed so that no learner is excluded due to varying digital experience levels.

ECVET/ECTS Credit Allocation

The 60 learning hours are distributed across different types of activities:

- **Lectures and instructional content**: 20 hours
- **Practical exercises and guided activities**: 15 hours
- **Independent study, reading, and assessment preparation**: 25 hours

The distribution of ECTS credits across modules is based on the relative weight and expected workload of each:

- **Module 1: Fundamentals of Energy Consumption in 5G Network** – 0.5 ECTS (15 hours)
- **Module 2: Energy Efficiency Techniques and Network Optimization** – 0.5 ECTS (15 hours)
- **Module 3: Renewable and Hybrid Energy Integration in 5G** – 0.5 ECTS (15 hours)
- **Module 4: Regulatory, Policy, and Market Perspectives** – 0.5 ECTS (15 hours)

This allocation reflects the expected time investment across **content acquisition, applied activities**, and **student-led learning**.

The higher ECTS allocation for Module 2 reflects its strong practical orientation and the integration of advanced modelling and optimisation techniques, which require more student-led application and analysis

5. Entrepreneurship and Innovation in Advanced 5G Technologies

General Information

Course Title	Entrepreneurship and Innovation in Advanced 5G Technologies
EQF Level	5
ECVET/ECTS Credits	2 ECTS
Total Learning Hours	60 hours
Audience	**Higher Education Students** in **STEM** fields (e.g., telecommunications, computer science, engineering, or digital

	technologies) who are interested in applying their technical knowledge to real-world innovation and entrepreneurial ventures in the 5G/B5G space. **Early-Career Professionals** working in telecom, digital infrastructure, IoT, or adjacent sectors who seek to understand how to commercialize technologies, navigate funding routes, and build start-ups around 5G-enabled solutions. **Researchers and PhD Candidates** aiming to valorise their work through tech transfer, IP protection, or start-up formation. **Aspiring Entrepreneurs** and **Start-up Founders** who are exploring 5G-related innovation opportunities and want a structured pathway to validate their ideas and build investor-ready ventures. **Innovation Officers and Project Managers** in universities, public institutions, and R&D centres interested in understanding the business potential and ecosystem integration of 5G technologies.
Prerequisites	• Basic knowledge of telecommunications or digital technologies • Awareness of entrepreneurship or innovation practices (desirable but not essential)
Language of Instruction	English
Coordinator	Gonca Kara
Course Title	Entrepreneurship and Innovation in Advanced 5G Technologies

Table 43. General info for the course 'Entrepreneurship and Innovation in Advanced 5G Technologies'

Course Description

This course is part of the 5G-DiGITs curriculum and aims to deliver a holistic and practical approach to entrepreneurship and innovation within the Beyond 5G (B5G) ecosystem. It equips learners with foundational and advanced knowledge, hands-on skills, and real-world abilities (KSA) aligned with Erasmus+ standards and the 5G-DiGITs educational methodology.

The course specifically supports future founders, innovators, and professionals working at the intersection of digital technologies and business creation, guiding them through opportunity recognition, lean validation, IP management, and start-up strategy development.

Learners will explore emerging market needs in the 5G sector and develop entrepreneurial competencies such as user-centred innovation, pitch delivery, IP strategy, business models, funding navigation, and go-to-market planning. Emphasis is placed on transforming technical knowledge into venture-ready solutions that align with societal and industry needs.

The programme is structured around three applied modules, each combining general knowledge, specific skills, and soft abilities in real-world 5G entrepreneurship contexts:

- **Module 1: From Ideas to Opportunities – Innovation in the 5G Landscape**

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Focuses on recognizing 5G-driven innovation opportunities, applying ideation tools and market research methodologies, and learning to build validated Minimum Viable Products (MVPs) through customer discovery.

- **Module 2: Building & Funding a 5G Start-up**

Covers early-stage venture management, business model development, start-up financing, and go-to-market planning for scalable 5G ventures.

- **Module 3: IP, Compliance, and Competitive Positioning in 5G Venture**

Equips learners with essential knowledge in intellectual property (IP), knowledge valorisation routes from academia, regulatory frameworks, and competitive strategies to scale responsibly.

Learners will engage in interactive sessions, start-up labs, investor simulations, and industry challenges, progressing from idea generation to a validated 5G venture plan, aligned with European market conditions and funding opportunities.

Detailed Learning objectives (instructor-oriented)

Module	Learning Objectives
Module 1 **From Ideas to Opportunities – Innovation in the 5G Landscape**	• Recognize innovation opportunities in the 5G ecosystem and identify unmet needs. • Apply opportunity mapping tools and value proposition design tailored for emerging 5G services. • Learn to use Design Thinking and lean start-up methods for early-stage 5G ventures. • Understand how to conduct customer discovery and translate feedback into testable MVPs. • Become familiar with the innovation ecosystem concept and 5G-driven business trends.
Module 2 **Building & Funding a 5G Start-up**	• Learn to develop a viable and fundable 5G business model using tools like the Business Model Canvas. • Learn how to evaluate and compare start-up funding strategies, including grants, VC, and crowdfunding. • Learn how to align financial strategy with customer and market requirements. • Learn to design a go-to-market strategy, including sales, marketing, and launch execution plans. • Become more prepared for leadership and teamwork in start-up development contexts
Module 3 **IP, Compliance, and Competitive Positioning in 5G Ventures**	• Identify and apply appropriate IP protection strategies (patents, trademarks, licensing) for 5G ventures. • Understand different routes (licensing, spin-off, open innovation) and tools for knowledge valorisation

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	• Learn to align IP strategy with long-term competitive positioning. • Understand key legal and ethical considerations (GDPR, AI Act, telecom standards). • Learn to evaluate compliance risks and structure mitigation plans.

Table 44. Learning objectives for the course 'Entrepreneurship and Innovation in Advanced 5G Technologies'

Detailed Learning Outcomes (student-oriented)

By the end of this course, students will be able to:

Module	Learning Outcomes
Module 1 **From Ideas to Opportunities – Innovation in the 5G Landscape**	• Understand the mobile cellular system evolution, with a focus on 5G and its key components • Critically evaluate mobile system design rationale and evolution
Module 2 **Building & Funding a 5G Start-up**	• Understand 5G NR and RAN, spectrum allocation, transmission/reception protocols • Analyse how 5G NR/RAN design and configuration affect users' QoS/QoE performance • Evaluate 5G RAN security and privacy challenges Critically evaluate 5G end-to-end performance and bottlenecks, and possible improvement solutions
Module 3 **IP, Compliance, and Competitive Positioning in 5G Ventures**	• Understand 5G CN, QoS architecture, network slicing, and their enablers, e.g., SDN/NFV and MEC • Analyse how to leverage the above components for service delivery and performance enhancement • Evaluate 5G CN security and privacy challenges Critically evaluate 5G end-to-end performance and bottlenecks, and possible improvement solutions

Table 45. Learning outcomes for the course 'Entrepreneurship and Innovation in Advanced 5G Technologies'

The alignment between modules and KSA items is presented in the table below.

Module	Knowledge (General Competencies)	Skills (Specific Competencies)	Abilities (Soft Competencies)
Module 1 **From Ideas to Opportunities –**	- Turning Ideas into Products - Innovation &	- Ideation Tools - Market Research Methodology	- Navigate Innovation Ecosystems

Innovation in the 5G Landscape	Opportunity Mapping - Market Analysis & Customer Discovery	- Customer Validation	- Iterate Based on Feedback
Module 2 **Building & Funding a 5G Start-up**	- Early-Stage Venture Management - Business Models - Fundraising Strategy	- Business Model Tools - Go-To-Market Planning - Fundraising - Entrepreneurial Pitching	- Design & Defend a Start-up Plan - Build and Lead Entrepreneurial Teams
Module 3 **IP, Compliance, and Competitive Positioning in 5G Ventures**	- Intellectual Property (IP) & Tech Transfer - Knowledge Valorisation Routes - Regulatory and Ethical Strategy	- IP Strategy & Competitive Positioning - Ethical AI & Regulatory Compliance	- Apply IP & Regulatory Strategy - Design IP-aware Go-To-Market Paths

Table 46. Alignment between KSA items and modules for the course 'Entrepreneurship and Innovation in Advanced 5G Technologies'

Detailed Modules and Units

MODULE	Module1: From Ideas to Opportunities – Innovation in the 5G Landscape
UNIT	**Unit 1: Recognizing Innovation Opportunities in 5G**
Learning Hours x	5 hours
Learning Outcomes	Learners understand how to turn ideas into 5G-related products by identifying needs, mapping opportunities, and using tools like design thinking, trend analysis, and value proposition design. They gain skills in creative problem-solving and strategic thinking to develop user-focused innovations.
Teaching methods	Lectures, Design Thinking Labs, Ideation Workshops, Independent Study
Assessment methods	Opportunity Mapping Canvas (focus on own business idea or a case study from the industry), Tool Proficiency Test (multiple choice questions)
Prerequisites	None
UNIT	**Unit 2: Validating Ideas through User Research and MVP Testing**
Learning Hours	10 hours
Learning Outcomes	Learners understand how to analyse markets, discover customer needs, and validate 5G-related ideas through real-world market

	research and iterative feedback. They apply tools like lean start-up validation techniques, interviews, segmentation, and MVP testing, while building familiarity with innovation ecosystems, incubators, and accelerators. This strengthens their ability to design user-focused, adaptable solutions aligned with 5G-driven opportunities.
Teaching methods	User Research Sprints, Case Studies, Fieldwork, Start-up Simulations
Assessment methods	MVP Testing Exercise (for own business idea or a case study from the industry, should include a plan, techniques, and initial market feedback), Peer Review
Prerequisites	Unit 1 of Module 1

Table 47. Module 1 for the course 'Entrepreneurship and Innovation in Advanced 5G Technologies'

MODULE	**Module 2:** Building & Funding a 5G Start-up
UNIT	**Unit 1: Business Modelling for 5G-Enabled Start-ups**
Learning Hours x	12 hours
Learning Outcomes	Learners understand how to establish and lead early-stage ventures by forming effective interdisciplinary teams, setting up operations, and securing foundational resources. They explore business model development using tools like the Business Model Canvas, revenue models, and financial forecasting to align innovation with long-term sustainability. Through leadership practices and lean start-up principles, learners build the confidence to navigate the complexities of establishing a business in fast-moving 5G sectors.
Teaching methods	Canvas Workshops, Financial Planning Labs, Case Studies, Independent Study
Assessment methods	Business Model Canvas Presentation (based on own idea or a case study from the industry), Reflection on Building Start-up Capabilities (1-2 pages)
Prerequisites	None
UNIT	**Unit 2: Start-up Funding & Go-to-Market Strategy**
Learning Hours	10 hours
Learning Outcomes	Learners understand how to develop and communicate a comprehensive start-up strategy, from identifying funding pathways to launching go-to-market plans. They gain hands-on experience in preparing investor-ready documentation, storytelling, crafting persuasive pitches, and aligning capital needs with appropriate fundraising models such as grants, equity, and

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	crowdfunding. By designing and defending a full start-up plan, learners build the skills to confidently present their business case to investors and stakeholders.
Teaching methods	Lectures, Case studies, Pitch deck reviews, Networking Sessions, Investor simulations (a simulation exercise with the pitch deck)
Assessment methods	Pitch deck (based on own business idea or a case study from the industry, including the GTM strategy and funding needs), Investment Opportunity Report (includes at least 5 identified funding sources), Mock pitching exercise self-assessment reflection
Prerequisites	Unit 1 of Module 2

Table 48. Module 2 for the course 'Entrepreneurship and Innovation in Advanced 5G Technologies'

MODULE	**Module 3:** IP, Compliance, and Competitive Positioning in 5G Ventures
UNIT	Unit 1: Intellectual Property and Tech Transfer in Telecom & Digital
Learning Hours x	13 hours
Learning Outcomes	Learners understand how to protect and commercialize innovations by applying core concepts of intellectual property, including patents, copyrights, and licensing. They develop strategies for tech transfer and knowledge valorisation, learn about routes such as spin-offs, licensing, and open innovation, and learn to use tools like patent databases and IP landscape analysis to strengthen competitive positioning.
Teaching methods	IP Clinics, Tech Transfer Case Reviews, Guest Lectures
Assessment methods	IP Strategy exercise (based on own business idea or a case study from the industry, includes identifying the IP, necessary tools, insights from tool use, and competitive positioning)
Prerequisites	None
UNIT	**Unit 2: Compliance, Ethics, and Responsible Scaling**
Learning Hours	10 hours
Learning Outcomes	Learners understand how to navigate legal and ethical frameworks in the deployment of AI and 5G technologies, focusing on data privacy (e.g., GDPR), telecom regulations, and responsible innovation. They gain the ability to conduct compliance audits, align with digital ethics principles, and integrate regulatory considerations into go-to-market strategies. This equips them to design scalable, IP-aware commercialization paths that meet both legal standards and market expectations.

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Teaching methods	Ethics Roundtables, Compliance Role-Plays, Regulatory Deep-Dives
Assessment methods	Regulatory Alignment Plan (for own business idea or a case study from the industry), Compliance Simulation (for a case study from the industry)
Prerequisites	Unit 1 of Module 3

Table 49. Module 3 for the course 'Entrepreneurship and Innovation in Advanced 5G Technologies'

Learning and Teaching Methods

This course integrates innovative pedagogy and practical tools to foster entrepreneurial thinking and applied innovation:

- Problem-Based Learning (PBL)
- Design Thinking Workshops
- Business Model Simulation Exercises
- Guest Lectures by Entrepreneurs & IP Experts
- Role-Playing and Pitch Practice
- Collaborative Project Work
- Independent Research and Reflection

Work-Based Learning

The course promotes real-world entrepreneurship experience by engaging learners in simulated startup environments:

- Execution of customer interviews and ecosystem mapping
- Development of validated 5G MVPs using lean startup tools
- Mock pitching to simulate early-stage fundraising rounds
- Identification of IP protection needs and market entry risks

Digital Competencies

Students build strong digital literacy through the use of modern business and research tools:

- Use of business planning platforms (Lean Canvas, BMC)
- Online collaboration via tools like Miro, Trello, Notion
- Market and IP analysis using databases (e.g., Espacenet, Crunchbase)
- Digital pitching and storytelling using presentation software
- Data-driven decision-making using basic financial modeling tools

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Assessment and Feedback Mechanism

Assessments reflect both academic and entrepreneurial performance criteria:

- Opportunity Mapping and Tool Proficiency
- MVP Validation and Market Feedback
- Business Model, Pitch Deck, and Presentations
- Regulatory and IP Analyses

Feedback Mechanism:

- Automated feedback for MCQs

- Instructor feedback for written assessments

- Peer reviews for the MVP testing exercise

- Mentor feedback from industry experts

- Self-assessment reflections (pitch presentation)

Recommended readings

Module 1:

- *Design a Better Business* by Patrick van der Pijl
- *The Lean Startup* by Eric Ries
- Selected 5G innovation case studies

Module 2:

- *Business Model Generation* by Osterwalder & Pigneur
- *HBR Guide to Raising Startup Capital*
- Case studies of GTM plans from the telecom sector

Module 3:

- *Intellectual Property for Entrepreneurs* by Eva-Maria Kieninger
- *AI Ethics and Data Protection* whitepapers
- EU documents on telecom regulatory compliance

Capstone:

- *Venture Deals* by Brad Feld & Jason Mendelson
- Reports from EIC, EIT Digital, and Horizon Europe on startup funding

Development of Soft Skills

The course places strong emphasis on interpersonal and entrepreneurial skill development:

- Startup simulations including peer feedback
- Strategic decision-making exercises
- Pitching exercises

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- Ecosystem engagement through Case Studies
- Reflective practice on resilience, leadership, and adaptability

Industry Collaboration and Internships

The course provides strong industry exposure through:

- Guest talks from startup founders and venture builders
- Expert-led IP and funding mentorship labs
- Real-world challenge briefs and case studies from industry stakeholders
- Networking sessions with industry, accelerators, and investors

Optional internship matching in telecom and innovation hubs

Accessibility and Inclusivity

Course is designed with inclusivity and flexibility in mind:

- Subtitles and translated materials where needed
- Assistive tech support for learners with disabilities
- Open-access digital tools and resources
- Flexible group formations and peer-based learning

ECVET/ECTS Credit Allocation

Total credits: **2 ECTS** (60 hours)

- Module 1: 0.5 ECTS (15h)
- Module 2: 0.83 ECTS (25h)
- Module 3: 0.66 ECTS (20h)

6. Digital Skills for Beyond 5G Technologies

General Information

Course Title	Digital Skills for Beyond 5G Technologies
DoA Learning Outcomes	• Acquire advanced digital skills for working with 5G technologies (LO1) • Apply data analytics, visualisation, machine learning, and AI techniques in 5G contexts (LO2) • Understand cybersecurity challenges and solutions in 5G networks (LO3)

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EQF Level	6
ECVET/ECTS Credits	2 ECTS
Total Learning Hours	60 hours (This aligns with the ECTS standard workload assumption of 25–30 hours per credit) Structure: • 20 hours of lectures, • 15 hours of practical exercises • 25 hours of independent study
Audience	HEI students in ICT and engineering programs, as well as early-career professionals and entrepreneurs seeking advanced 5G skills, particularly learners with a technical profile or with prior familiarity with telecommunications, data analytics, and digital systems.
Prerequisites	• Basic knowledge of telecommunications and networking • Basic programming and data analytics skills • Mathematical and analytical skills • Basic cybersecurity awareness • General technical proficiency The course is best suited to learners able to follow applied technical examples in network analysis, AI/ML, and cybersecurity contexts.
Language of Instruction	English
Coordinator	Francisco Javier García Gómez

Table 50. General info for the course 'Digital Skills for Beyond 5G Technologies'

Course Description

This course is part of the 5G-DiGITs curriculum and focuses on developing advanced **digital skills** relevant to deploying, optimising, and securing Beyond 5G (B5G) technologies. It follows the **KSA (Knowledge, Skills, Abilities)** methodology and is aligned with **Erasmus+ principles**, including EQF level referencing, ECTS-based credit allocation, and learning outcomes-based curriculum design.

Through a structured, hands-on approach, learners will gain technical capabilities in 5G network design, data analytics, AI integration, and cybersecurity. This learning path should be supported by clearer guided application, stronger visual support, and more consistent practical scaffolding across modules.

The course content is structured around three thematic modules covering (i) **Digital skills for 5G deployment and optimisation, (ii) AI and data analytics in 5G systems, and (iii) Cybersecurity challenges and solutions in 5G.** This overall structure remains valid and should be preserved,

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while the implementation should focus on the differentiation and usability of the learning experience across the three modules.

A practical, problem-based learning approach supports the development of industry-relevant competencies through case studies, simulations, and lab-based exercises. This practice-oriented approach should be made visible through clear examples, good signposting of activities in the LMS, and strong support for the connection between theory and application.

Detailed Learning objectives (instructor-oriented)

Module	Learning Objectives
Module 1 **Advanced digital skills for working with 5G technologies**	Enable students to: • Explain the evolution of 5G and Beyond 5G (B5G) technologies, including key concepts such as spectrum management and energy-efficient networking in modern telecommunications. • Describe the core architecture of 5G networks, including network components and the integration of data analytics for real-time performance monitoring and digital network management. • Identify the essential technical skills required to design, deploy, and manage 5G network infrastructures, with an emphasis on data processing and network optimisation in virtualised and data-driven environments.
Module 2 **Machine learning, AI integration, and data analytics in 5G**	Enable students to: • Apply data analytics tools to analyse large-scale telecom data for insights into network performance and optimisation. • Understand the role of machine learning (ML) and artificial intelligence (AI) in optimising 5G network operations, including predictive maintenance and traffic management. • Implement machine learning algorithms for real-time decision-making, resource allocation, and network optimisation in 5G environments and relate these to intelligent network management scenarios.
Module 3 **Cybersecurity challenges and solutions in 5G networks**	Enable students to: • Identify key cybersecurity threats to 5G networks, assess potential risks, and understand their impacts on telecom infrastructures • Evaluate advanced security solutions for 5G networks, including Zero Trust models and Post-Quantum Cryptography (PQC). • Apply cybersecurity best practices to secure both virtual and physical components of 5G networks and support secure, compliant, and industry-relevant 5G deployment scenarios.

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Cross-cutting Abilities (Soft Competencies, applicable to the 3 previous modules)	Enable students to: • Critically analyse and communicate 5G technology solutions in multidisciplinary team environments • Assess ethical and operational trade-offs when implementing AI and data-driven solutions within 5G ecosystems and when addressing cybersecurity and compliance requirements in practical contexts

Table 51. Learning objectives for the course 'Digital Skills for Beyond 5G Technologies'

Detailed Learning Outcomes (student-oriented)

By the end of this course, students will be able to:

Module	Learning Outcomes
Module 1 **Advanced digital skills for working with 5G technologies**	1. **Describe** the evolution from 5G to Beyond 5G (B5G), including spectrum management and energy-efficient networking principles 2. **Explain** the architecture of 5G networks, including virtualisation, cloud-native components, and integration with edge and IoT technologies 3. **Apply** data visualisation tools to interpret and communicate real-time network performance metrics in a clear and decision-relevant way 4. **Deploy** and manage virtualised environments using technologies such as NFV and SDN within a 5G context and relate them to practical network-operation scenarios
Module 2 **Machine learning, AI integration, and data analytics in 5G**	5. **Analyse** telecom data using data analytics techniques to derive actionable insights for network optimisation 6. **Implement** machine learning algorithms in 5G networks for predictive maintenance, dynamic resource allocation, and performance improvement 7. **Demonstrate** the integration of cloud, AI, and edge computing technologies to support scalable, intelligent 5G applications and applied optimisation use cases
Module 3 **Cybersecurity challenges and solutions in 5G networks**	8. **Evaluate** cybersecurity risks in 5G infrastructure and apply mitigation strategies using encryption, authentication, and zero-trust models 9. **Interpret** and apply legal, ethical, and regulatory frameworks (e.g., GDPR, AI Act) relevant to data privacy and AI-driven 5G systems

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	Design secure, industry-compliant 5G architectures tailored to real-world scenarios and stakeholders with attention to both technical and organisational requirements

Table 52. Learning outcomes for the course 'Digital Skills for Beyond 5G Technologies'

The alignment between modules and KSA items is presented in the table below.

Module	Knowledge (General Competencies)	Skills (Specific Competencies)	Abilities (Soft Competencies)
Module 1 **Advanced digital skills for working with 5G technologies**	**Fundamentals of 5G and Beyond 5G Technologies**: Understanding 5G network architecture, key concepts such as network slicing, spectrum management, and Beyond 5G technologies **IoT and Edge Computing in 5G Ecosystems**: Know how IoT devices and edge computing technologies integrate with 5G to provide low-latency and real-time applications **Cloud Computing and 5G**: Awareness of how cloud computing integrates with 5G networks, including Multi-Access Edge Computing (MEC) for optimised service delivery	**Setting Up and Managing Virtualized 5G Environments:** Practical experience implementing and managing network functions virtualisation (NFV) and software-defined networking (SDN) for 5G **Data Visualization for 5G Networks**: Visualise 5G network performance data using specialised tools, ensuring that stakeholders can understand complex operational metrics **Troubleshooting 5G Network Issues** Diagnose and resolve issues within 5G networks, including network performance,	**Designing an Efficient and Scalable 5G Infrastructure**: Design and implement a scalable, efficient, and well-structured 5G network infrastructure **Leading Innovation in Beyond 5G Technologies**: Lead projects and initiatives focused on developing and deploying 5G and Beyond 5G technologies **Analysing Industry-Specific 5G Applications**: Analyse and design 5G solutions tailored to specific industries (e.g., healthcare, automotive, smart cities)

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		connectivity, and device malfunctions	
Module 2 **Machine learning, AI integration, and data analytics in 5G**	**Machine Learning and AI Applications in 5G**: Knowledge of AI-driven solutions for network optimisation, predictive maintenance, and dynamic resource allocation in 5G environments **Advanced data analytics and AI-supported interpretation in 5G**: Understanding advanced analytics methodologies and AI-supported techniques to process, interpret, and present telecom data from 5G networks. **Future Trends and Applications of Beyond 5G Technologies:** Knowledge of emerging technologies that will influence the future of 5G, including AI, machine learning, and IoT integrations	**Implementing Machine Learning in 5G**: Apply machine learning algorithms to enhance the performance of 5G networks, such as optimising traffic and resource allocation **Cloud Integration for 5G Applications:** Integrate cloud-based services with 5G to enable scalable applications, with a particular focus on the role of MEC in 5G networks **Ethical AI Decision-Making in 5G Systems**: Applying ethical principles to AI-driven decision-making within 5G systems to ensure fairness and accountability	**Optimizing 5G Networks Using AI**: Optimise the operation of 5G networks using AI-based techniques for improved resource allocation and network efficiency **Integrating IoT, AI, and Edge Computing in 5G**: Design and implement solutions integrating IoT devices, AI, and edge computing in 5G networks to support real-time applications **Implementing Sustainable and Energy-Efficient 5G Networks**: Design energy-efficient 5G networks that minimise environmental impact while maintaining performance
Module 3 **Cybersecurity challenges and solutions in 5G networks**	**Cybersecurity in 5G Networks** Understanding of cybersecurity threats specific to 5G, including the challenges posed by network vulnerabilities, zero-trust models, and	**Securing a 5G Network**: Implement security measures, such as encryption and authentication protocols, to protect 5G	**Evaluating Cybersecurity Threats in 5G**: Conduct thorough evaluations of potential security threats and recommend

	quantum-safe encryption **Regulatory and Ethical Considerations in AI-Driven 5G:** Knowledge of the ethical, legal, and regulatory issues concerning AI and data privacy within 5G networks, including relevant compliance frameworks **Network slicing and virtualisation security in 5G**: F Familiarity with the concept of network slicing and the role of virtualisation in improving network security, isolation, and resilience	networks from cyber threats. Identify and assess cybersecurity threats in 5G networks and develop strategies to mitigate these risks **Configuring secure endpoints and connected devices in 5G environments:** Securely configure connected devices and endpoints within 5G networks, ensuring protected communication, access control, and reliable integration with the network environment	solutions for 5G network protection **Implementing Ethical and Regulatory Compliance in 5G Applications**: Ensure that 5G applications comply with regulatory frameworks and ethical standards for data privacy and AI usage. Design secure 5G infrastructures that meet the needs of diverse industries while remaining compliant with legal and ethical standards

Table 53. Alignment between KSA items and modules for the course 'Digital Skills for Beyond 5G Technologies'

Detailed Modules and Units

MODULE	Module 1: Advanced digital skills for working with 5G technologies
UNIT	**Unit 1: Introduction to 5G Technologies**
Learning Hours	10 hours
Learning Outcomes	By the end of this unit, students will be able to: • Explain the core concepts of 5G and Beyond 5G (B5G) technologies • Apply the principles of network slicing and spectrum management in B5G environments • Evaluate the role of energy-efficient networking in the future of 5G and B5G

Teaching methods	Lectures, case studies, and practical exercises supported by clear examples and short guided activities that connect core concepts with realistic network scenarios
Assessment methods	MCQs (40%), short essays (60%). Assessment tasks should be clearly signposted in the LMS and framed with concise guidance on scope and expected effort.
Prerequisites	None
UNIT	**Unit 2: Data Analytics and Visualisation in 5G Networks**
Learning Hours	10 hours
Learning Outcomes	By the end of this unit, students will be able to: • Implement data visualisation techniques for displaying 5G network performance • Analyse and interpret telecom data using visualisation tools • Evaluate the role of data-driven decision-making in optimising 5G networks
Teaching methods	Lectures, practical data visualisation tools (e.g., Power BI, Tableau), and practical exercises with stronger visual support and guided examples showing how dashboards and performance indicators are interpreted in practice
Assessment methods	Practical project (creating and presenting a data visualisation dashboard for 5G network performance) (100%). The project brief should clearly indicate the required outputs, evaluation criteria, and indicative time commitment.
Prerequisites	Unit 1 or equivalent understanding of 5G fundamentals

Table 54. Module 1 for the course 'Digital Skills for Beyond 5G Technologies'

MODULE	**Module 2**: Machine learning, AI integration, and data analytics in 5G
UNIT	**Unit 3: Machine Learning and AI in 5G Networks**
Learning Hours	10 hours
Learning Outcomes	By the end of this unit, students will be able to: • Describe how machine learning and AI are applied to 5G networks for performance optimisation • Identify the key components of AI-driven network optimisation in B5G environments

	• Assess the impact of machine learning on dynamic resource allocation in 5G
Teaching methods	Lectures, demonstrations (showcasing AI applications in network optimisation), case studies, and short step-by-step examples that help learners relate AI concepts to concrete telecom optimisation tasks.
Assessment methods	Project (implementing a basic AI algorithm for network optimisation) (70%), short essay (on AI applications in network resource management) (30%). These activities should remain manageable in scope and be clearly connected to the practical examples developed during the unit.
Prerequisites	Unit 1 of Module 1 or a basic understanding of 5G technologies
UNIT	**Unit 4: Advanced Data Analytics Techniques in 5G**
Learning Hours	5 hours
Learning Outcomes	By the end of this unit, students will be able to: • Apply machine learning algorithms to telecom data for predictive maintenance in 5G networks • Visualize machine learning results and insights to enhance decision-making processes • Analyse real-time data streams and perform network diagnostics using machine learning techniques
Teaching methods	Lectures, practical exercises using Python or R, and practical data analytics tools supported by clearly sequenced tasks and examples that make the transition from theory to applied diagnostics easier to follow
Assessment methods	Practical project (applying machine learning techniques to analyse 5G network data) (70%), presentation (showing how machine learning insights influence network management) (30%). As this is a short unit, the assessment should remain tightly bound and proportionate to the 5-hour allocation
Prerequisites	Unit 3.

Table 55. Module 2 for the course 'Digital Skills for Beyond 5G Technologies'

MODULE	**Module 3**: Cybersecurity challenges and solutions in 5G networks
UNIT	**Unit 5: Fundamentals of Cybersecurity in 5G Networks**
Learning Hours	10 hours
Learning Outcomes	By the end of this unit, students will be able to:

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	• Explain the cybersecurity challenges unique to 5G networks. • Evaluate security risks in 5G network infrastructures. • Apply cybersecurity frameworks, including Zero Trust, to 5G networks
Teaching methods	Lectures, practical case studies, and exercises on security protocols. This unit should continue to combine conceptual grounding with applied security reasoning through realistic scenarios and guided case interpretation
Assessment methods	Case study analysis (60%), MCQs (40%). The distinction between formative checking and case-based application should be made clear to learners from the start of the unit
Prerequisites	Basic knowledge of cybersecurity principles (covered in Module 2 or prior knowledge).
UNIT	**Unit 6: Advanced Cybersecurity Solutions for 5G**
Learning Hours	15 hours
Learning Outcomes	By the end of this unit, students will be able to: • Implement ethical AI models in securing 5G networks • Design and deploy security measures such as encryption, authentication, and access control in 5G environments • Evaluate the legal and regulatory compliance needs in securing 5G networks
Teaching methods	Lectures, practical exercises, and some discussions on Ethical AI. Given the greater weight of this unit, its implementation should place particular emphasis on clear sequencing, realistic examples, and explicit links between technical security measures, ethical AI issues, and compliance requirements
Assessment methods	Practical security project (setting up a secure 5G network environment) (70%), ethical compliance report (30%). Because this is the heaviest unit in the course, the expected outputs, deliverables, and indicative effort should be especially clear and carefully bounded
Prerequisites	Unit 5 or prior experience with cybersecurity measures

Table 56. Module 3 for the course 'Digital Skills for Beyond 5G Technologies'

Mapping of Learning Outcomes to Teaching and Assessment Methods

The following table presents a detailed tentative mapping of the unit-level learning outcomes (LOs) to their associated teaching methods, assessment methods, and relative weighting.

Each learning outcome is labelled using the format **LOX.Y**, where **X** refers to the unit number (e.g., Unit 1 = 1) and **Y** refers to the outcome's sequence within that unit (e.g., **LO1.2** is the

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second learning outcome in Unit 1). The percentage shown in the *Weight* column expresses the share of the assessment for **each individual learning outcome (LO)** that is provided by the listed assessment method. A value of **100 %** means that the LO is evaluated exclusively through that single instrument, whereas lower percentages indicate that several assessment tools jointly determine the final mark for that LO. Because weights are defined *per outcome*, they are **not intended to sum to 100 % across the whole table**; rather, they highlight the relative importance of each piece of evidence for demonstrating the specific competence targeted by the outcome.

This mapping is intended to provide transparency and alignment between intended outcomes, instructional strategies, and evaluation components, ensuring consistency with the 2 ECTS (60-hour) structure of the course.

LO Code	Learning Outcome	Teaching Methods	Assessment Method	Weight
LO1.1	Explain the core concepts of 5G and B5G technologies	Lectures, case studies, practical exercises, and guided examples	MCQs	40%
LO1.2	Apply network slicing and spectrum management in B5G	Lectures, case studies, practical exercises, and guided examples	Short essays	60%
LO1.3	Evaluate the role of energy-efficient networking	Lectures, case studies, practical exercises, and guided examples	Short essays	60%
LO2.1	Implement data visualisation for 5G performance	Labs and guided dashboard exercises (Power BI, Tableau)	Project	100%
LO2.2	Analyse telecom data with visual tools	Labs and guided dashboard exercises (Power BI, Tableau)	Project	100%
LO2.3	Evaluate data-driven decision-making in 5G	Labs and guided dashboard exercises (Power BI, Tableau)	Project	100%
LO3.1	Describe ML/AI use in 5G	Lectures, demonstrations, case studies, and guided optimisation examples	Short essay	30%
LO3.2	Identify AI components in B5G optimisation	Lectures, demonstrations, case studies, and guided optimisation examples	Project	70%
LO3.3	Assess the impact of ML on resource allocation	Lectures, demonstrations, case studies, and guided optimisation examples	Project	70%

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LO4.1	Apply ML to telecom data for predictive maintenance	Python/R labs and guided data-diagnostics exercises	Project	70%
LO4.2	Visualise ML insights for decision-making	Python/R labs and guided data-diagnostics exercises	Presentation	30%
LO4.3	Analyse real-time data and diagnostics	Python/R labs and guided data-diagnostics exercises	Project	70%
LO5.1	Explain cybersecurity challenges in 5G	Lectures, security exercises, and guided case analysis	MCQs	40%
LO5.2	Evaluate 5G security risks	Lectures, security exercises, and guided case analysis	Case study	60%
LO5.3	Apply frameworks like Zero Trust	Lectures, security exercises, and guided case analysis	Case study	60%
LO6.1	Implement ethical AI models in 5G security	Lectures, ethics discussions, and applied compliance scenarios	Security project	70%
LO6.2	Deploy encryption/authentication mechanisms	Lectures, labs, and guided security-configuration exercises	Security project	70%
LO6.3	Evaluate legal/regulatory compliance	Lectures, ethics discussions, and applied compliance scenarios	Compliance report	30%

Table 57. Mapping of LOs to Teaching and Assessment Methods for the course 'Digital Skills for Beyond 5G Technologies'

Tentative Workload Distribution by Unit

The course is structured to meet the Erasmus+ workload standard of **60 hours for 2 ECTS**, with a typical distribution of:

- **20 hours of lectures**
- **15 hours of exercises or lab-based work**
- **25 hours of self-study**

This proportion is used **consistently across all units**, though **minor adjustments may occur during course implementation**. The table below summarizes the planned breakdown by unit.

Unit	Total Hours	Lectures	Exercises	Self-Study

Unit 1: Introduction to 5G Technologies	10	3.3	2.5	4.2
Unit 2: Data Analytics & Visualisation in 5G	10	3.3	2.5	4.2
Unit 3: ML and AI in 5G	10	3.3	2.5	4.2
Unit 4: Advanced Data Analytics in 5G	5	1.7	1.3	2.1
Unit 5: Fundamentals of Cybersecurity in 5G	10	3.3	2.5	4.2
Unit 6: Advanced Cybersecurity for 5G	15	5.0	3.8	6.3
Total	**60**	**20**	**15**	**25**

Table 58. Tentative workload distribution by unit for the course 'Digital Skills for Beyond 5G Technologies'

Learning and Teaching Methods

This course combines traditional and new teaching techniques to attain a complete and real-world understanding of Beyond 5G technologies, machine learning and AI solutions, data analysis, and 5G network security. The learning process should make the connection between theoretical explanation and applied practice more visible through clear examples, strong visual support, and well-signposted activities in the LMS. The following techniques are combined in the learning process:

- Problem-Based Learning (PBL): Students will work with real-world issues related to 5G networks, data analysis, and security attacks. This technique encourages critical thinking and experiential problem-solving. Short, guided tasks and realistic examples should help learners move from conceptual understanding to applied analysis and decision-making.
- Case Study Analysis: Industry-specific case studies of 5G rollouts, AI-driven optimisations, cyber-attacks, and data analytics solutions will be analysed by the students to learn how the concepts are applied in real-life scenarios. These case-based activities should be supported by clearer practical framing and by examples that show how the analytical steps relate to realistic 5G contexts.
- Practical Exercises: Simulation and guided lab sessions will allow the students to perform hands-on exercises in setting up IoT devices, building virtualised 5G labs, deploying machine learning models, and installing cybersecurity solutions. Practical exercises should remain central, with stronger step-by-step guidance where needed, especially in areas such as data interpretation, AI-supported optimisation, anomaly detection, and security analysis.
- Interactive Lectures: discussions, online Q&A, and demonstrations will be conducted in lectures to create an interactive learning environment where students are actively engaged in learning about Beyond 5G technologies, AI-based 5G enhancements, and secure networking concepts. Presentation materials and audiovisual delivery should support engagement through reduced text density, improved visual hierarchy, clearer pronunciation of technical terms, and stronger explanatory use of diagrams, figures, and examples.
- Work-Based Learning: Students will apply theoretical principles to actual projects, including designing AI-driven 5G solutions, evaluating security threats, and visualising network performance. These applied activities should be clearly connected to the

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corresponding modules and supported by concise guidance on expected outputs and scope.

- Independent Study: Structured reading materials, research assignments, and online resources will help students take their learning outside the classroom, preparing them for exams and real-life applications. Independent study should also be supported by clearer signposting of materials, more visible module progression, and concise guidance that helps learners distinguish between core and complementary resources.

This blended method ensures students get a strong theoretical foundation while developing hands-on skills in advanced digital capabilities for Beyond 5G technologies. The implementation should preserve this structure while strengthening engagement, guided practical learning, and the overall usability of the learner pathway.

Work-Based Learning

Practical learning in this course includes lab sessions, practical training, and individual study, enabling students to gain world-class expertise on Beyond 5G technologies. Scenario-based problem-solving will enable students to implement what they learn on industrial problems, such as:

- Configuring IoT and edge computing devices in 5G networks
- Deploying AI and machine learning models to optimise 5G network performance
- Implementing cybersecurity solutions to secure 5G infrastructure
- Interpreting and visualising network data for performance monitoring and decision-making
- Creating energy-efficient and sustainable network solutions

These applied tasks should be introduced with clear practical framing and concise guidance, so that learners can more easily understand the objective, scope, and professional relevance of each activity.

These experiences enable students to be capable of converting theoretical knowledge into practical skills, ready for entry into professional careers in advanced digital technologies, AI-driven telecom solutions, and secure network management. They should also help learners connect technical analysis with realistic decision-making scenarios in network deployment, optimisation, monitoring, and cybersecurity.

Work-based learning in this course is delivered primarily through structured, project-based activities and scenario-driven simulations conducted within the digital classroom environment. These activities mirror real-world professional contexts in 5G, AI, and cybersecurity domains and should be supported by good signposting of activities in the LMS, together with clear indication of expected outputs where relevant. Where possible, students are also encouraged to pursue internships or industry collaborations to apply their skills in live operational settings, as described in Section 12.

Digital Competencies

This course aims to develop upper-level digital competencies for handling Beyond 5G (B5G) technologies. Students will gain both theoretical knowledge and practical experience with a range of advanced tools and platforms across multiple domains. These competencies should be

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developed through a clear connection between digital tools, applied tasks, and the interpretation of results in realistic 5G scenarios:

- **Network simulation and virtualisation**: Students will engage with software for 5G network simulation, virtualised environments, and network slicing techniques to understand the structure and behaviour of next-generation network systems. Practical use of these environments should be supported by clear examples and by guidance that links configuration choices to network behaviour and performance.
- **Data analytics and visualisation**: The course introduces platforms used for real-time network monitoring, predictive analytics, and data-driven decision-making within 5G ecosystems. Learners should be supported in interpreting dashboards, indicators, and analytics outputs so that visualisation is connected to diagnosis, optimisation, and decision-making.
- **AI-driven automation and machine learning**: Learners will use machine learning platforms to enhance network performance and automate key operational processes. These activities should make visible how AI and ML tools support optimisation, anomaly detection, and intelligent network management in applied telecom contexts
- **Cybersecurity technologies**: Core topics include Zero Trust security architectures, threat detection, encryption techniques, and the ethical considerations surrounding AI-driven 5G environments. The use of security-related tools and frameworks should be connected clearly to realistic risk assessment, protection, and compliance scenarios.
- **Cloud-native environments and Multi-Access Edge Computing (MEC)**: Students will work with modern deployment environments that enable low-latency and efficient 5G service delivery. These environments should be presented not only conceptually but also through applied examples that clarify their operational role in Beyond 5G systems.
- **E-learning and collaborative ICT tools**: Throughout the course, students will engage with digital learning platforms and collaborative tools, supporting teamwork, communication, and a fully connected learning experience. Their use in the LMS should also support clearer navigation, better activity signposting, and improved visibility of expected outputs.

By acquiring and applying these digital competencies, students will be well-equipped to thrive in the evolving professional landscape of Beyond 5G technologies. The implementation should preserve this breadth of digital competences while making their practical application more visible, better guided, and easier to transfer across modules.

Assessment and Feedback Mechanism

The assessment methods utilised in this course aim to evaluate students' knowledge, skills, and competencies in an integral and well-rounded manner. The assessment aligns with the learning results and allows students to demonstrate their expertise in the most significant areas of the course. The assessment pathway should remain clear, proportionate to the 2 ECTS workload, and closely connected to the practical learning activities developed across the modules. The assessment methods include the following:

- **Multiple-Choice Questions (MCQs)** will be used to assess students' understanding of foundational principles related to 5G technologies, machine learning, AI integration, data analytics, and security. MCQs are designed to test recall and application of master principles and should function primarily as scalable, low-stakes checks of understanding.

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- **Short Answer Questions** will allow students to display their ability to give brief answers and apply what they know to specific situations in 5G applications. These tasks should remain concise and clearly focused on applied interpretation rather than extensive written production.
- **Problem-solving questions** will test students' analysis and critical thinking capabilities, asking them to present solutions to real-world problems concerning 5G network deployment, machine learning application scenarios, or cybersecurity threats. Where included, these questions should be clearly linked to the practical examples and guided activities developed during the course.
- **Short Essays/Reports** will allow students to go in-depth about a specific topic, critically analysing current trends or challenges in 5G technologies and offering well-reasoned arguments based on evidence. Their scope should remain carefully bounded and appropriate to the total course workload.
- **Projects** will be used to assess how efficiently students can link theoretical knowledge to real-world issues. Students will create a project (it could be based on an existing research project) integrating the knowledge, skills, and competencies gained throughout the course, e.g., an eco-friendly 5G network or machine learning-enabled device for 5G network optimisation. Project-based tasks should be accompanied by clear indication of expected outputs, assessment criteria, and indicative effort.
- **Case Studies** will enable students to work through and resolve actual case situations in 5G, cybersecurity, or AI environments. Students will be expected to critically examine the case, suggest solutions, and support their reasoning with data and theoretical evidence. These activities should be framed with clear instructions and should support the connection between theory, analysis, and realistic professional scenarios.

The primary assessment methods emphasise scalability and automation, with MCQs, short answers, and structured problem-solving accounting for most grading weight. Project work and case studies may be offered optionally for learners in instructor-supported contexts or as capstone activities. This distinction should remain visible to learners from the start of the course, so that formative checks and larger applied tasks are clearly differentiated.

The feedback mechanisms will be the following:

- MCQs will be provided with immediate feedback to help students identify correct and incorrect responses.
- Instructor feedback for written exercises (e.g., essays, reports) will be given as personalised comments about strengths and weaknesses.
- The instructor will also provide case study feedback, allowing students to refine their analysis and recommendations.

Project feedback will be provided periodically throughout the process, updating students on their progress and advising them for the final submissions.

Where feasible, feedback should also support learner progression by making expectations, strengths, and areas for improvement explicit in relation to the practical goals of each task.

Recommended readings

The following readings are recommended to support learning in each module. These resources include foundational overviews, applied research, and state-of-the-art surveys relevant to Beyond 5G (B5G) technologies. Where available, links to open-access versions or institutional

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library access will be provided through the course platform. Supporting resources should be clearly linked to the corresponding module activities and presented in a way that helps learners distinguish between core readings and complementary materials.

Module 1 readings:

- The rise of 5G technologies and systems: a quantitative analysis of knowledge production (Telecommunications Policy, Volume 46, Issue 4, 2022, 102327, ISSN 0308-5961)
    - https://doi.org/10.1016/j.telpol.2022.102327https://www.sciencedirect.com/science/article/pii/S0308596122000301?via=ihub
- Asghar, M., Memon, S., & Hämäläinen, J. (2022). Evolution of Wireless Communication to 6G: Potential Applications and Research Directions. Sustainability.
    - https://doi.org/10.3390/su14106356.

Module 2 readings:

- Chatzoglou, E., & Goudos, S. (2023). Beam-Selection for 5G/B5G Networks Using Machine Learning: A Comparative Study. Sensors (Basel, Switzerland), 23.
    - https://doi.org/10.3390/s23062967.
- Duan, Y., Wu, Q., Zhao, X., & Li, X. (2024). Mobile edge computing based cognitive network security analysis using multi agent machine learning techniques in B5G. Comput. Electr. Eng., 117, 109181.
    - https://doi.org/10.1016/j.compeleceng.2024.109181.

Module 3 readings:

- Shafi, M., Jha, R., & Jain, S. (2023). Intelligent Trust Ranking Security Preserving Model for B5G/6G. IEEE Transactions on Network and Service Management, 20, 3549-3561.
    - https://doi.org/10.1109/TNSM.2023.3234319.
- Wang, J., Li, Y., Liu, J., & Kato, N. (2024). Intelligent Network Slicing for B5G and 6G: Resource Allocation, Service Provisioning, and Security. IEEE Wireless Communications, 31, 271-277.
    - https://doi.org/10.1109/MWC.021.2200589.

Development of Soft Skills

The course integrates soft skills development through various collaborative and reflective activities that also foster ethical awareness and cultural sensitivity in digital, AI-driven, and cybersecurity-related 5G contexts :

- **Team Projects**: Students collaborate on real-world 5G challenges in diverse, international teams, promoting teamwork, leadership, and the ability to work across cultures and disciplines. These projects often address global deployment scenarios, encouraging students to consider cultural, regulatory, and ethical differences in 5G implementation. Clear task framing and well-defined roles should support effective collaboration and shared responsibility.

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- **Verbal Presentations**: Learners present complex technical concepts related to 5G, AI, and cybersecurity to mixed audiences, including non-technical stakeholders. This hones public speaking, the ability to communicate across professional and cultural boundaries, and the skill of translating technical language into accessible messages. These activities should also help learners explain analytical results, risks, and design choices in a structured and audience-aware way.
- **Case Studies and Problem-Solving Exercises**: These activities expose students to ethically complex and culturally varied scenarios, such as privacy considerations in AI-powered 5G surveillance or access inequalities in rural deployments. Students develop critical thinking, ethical reasoning, and adaptability through guided interpretation of realistic scenarios and practical trade-offs.
- **Peer Review Activities**: Students evaluate and provide feedback on each other's work, learning to express constructive criticism and receive diverse perspectives respectfully, an essential skill in global professional environments. Where used, peer review should be supported by simple criteria to help students provide focused and useful feedback.
- **Ethical and Regulatory Discussions**: Integrated discussions address the implications of AI-driven 5G systems, covering topics like algorithmic bias, digital sovereignty, and responsible innovation. These foster students' professional responsibility and awareness of global ethical standards and cultural values in technology deployment.

These soft skills are embedded throughout the course structure and are cultivated via instructor feedback, collaborative practices, and self-reflective activities. Although not separately assessed, they are essential components of the holistic learning experience aimed at preparing students for global and ethically informed professional practice.

Industry Collaboration and Internships

Telecom and technology collaborations provide rich learning opportunities from the industry and practical exposure. Where institutional partnerships and resources allow, students are encouraged to engage in the following:

- **Industry guest lectures** by industry experts provide perspectives on future-looking 5G technologies, AI-driven network optimisation, cybersecurity threats, and directions Beyond 5G. These contributions can also help learners connect course concepts with current professional practices and technology trends.
- **Industrial internship** and workplace learning experiences allow students to put their cyber expertise into practice in industrial environments, using them to apply to occupation-specific duties such as 5G network data analysis, security threat research, and telecommunication infrastructures that integrate the cloud. Where feasible, such experiences should be understood as complementary opportunities rather than required components of the course.
- **Problem-based learning** and business partner case studies expose the learners to real-world experiences, industry insights, and current solutions, thereby eliminating the learning experience gap that occurs for certain theoretical topics. These case-based activities should remain the main bridge between the course and professional practice when direct industry participation is not available.
- **Networking and mentorship** with other professionals in the profession augment career growth and foster industry relationships.

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These collaborative opportunities are not guaranteed and depend on the specific institutional and regional context. They are offered when feasible and aim to enhance learner engagement with applied, occupation-specific experiences in the digital sector. Their value lies in reinforcing the practical and professional orientation of the course without changing its core online and modular structure.

Accessibility and Inclusivity

The course is designed to be inclusive and accessible to all learners, ensuring equal opportunities for participation and success.

- **Transcripts and subtitles** for video content provide accessibility for learners with hearing impairments and support those who prefer text-based learning. Visual and audiovisual materials should also be presented clearly, with good readability and improved support for the interpretation of diagrams, figures, and technical examples.
- Language support for non-native speakers, including **glossaries** of technical terms and AI-powered translation tools, facilitates comprehension for diverse learners. Where relevant, concise supporting resources and clearly signposted references should help learners distinguish between essential content and complementary material.
- **Flexible assessment formats**, such as oral presentations, written reports, and practical demonstrations, accommodate different learning preferences and needs.
- Customizable learning pace and materials, including **downloadable content** and asynchronous learning options, allow students to engage with the material at their own speed. Clear module progression, better grouping of materials in the LMS, and short orienting summaries should support learners in navigating the course more effectively
- Dedicated support for learners with disabilities, such as **extended assessment time** and **alternative task formats**, ensures an equitable learning experience.

These strategies reflect principles of Universal Design for Learning (UDL), promoting access and engagement for all learners regardless of background or ability. In addition, practical activities and applied tasks should be accompanied by clear instructions and well-signposted expectations so that learners can engage with them confidently and independently

ECVET/ECTS Credit Allocation

The total course is allocated 2 ECTS, distributed across modules as follows:

- Module 1: 0.66 ECTS (20 hours)

- Module 2: 0.5 ECTS (15 hours)

- Module 3: 0.83 ECTS (25 hours)

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7. Green Skills for Beyond 5G Technologies

General Information

Course Title	Green Skills for Beyond 5G Technologies
DoA Learning Outcomes	• Understand the environmental impact of 5G networks and eco-friendly design principles (LO1) • Apply circular economy concepts and sustainable materials in the 5G sector (LO2) • Recognise strategies for reducing the carbon footprint of 5G networks (LO3)
EQF Level	6
ECVET/ECTS Credits	2 ECTS
Total Learning Hours	60 hours (This aligns with the ECTS standard workload assumption of 25–30 hours per credit) Structure: • 20 hours of lectures, • 15 hours of practical exercises • 25 hours of independent study
Audience	Undergraduate and graduate students in engineering, ICT, sustainability, environmental studies, or related fields; early-career professionals and technical staff interested in sustainable telecommunications, green ICT, digital infrastructure, or regulatory and business aspects of the digital-green transition. The course is particularly suitable for learners seeking a specialized sustainability-oriented perspective within the Beyond 5G domain.
Prerequisites	• Basic understanding of digital communication systems • Basic familiarity with sustainability or environmental concepts is recommended • Interest in the intersection of technology, sustainability, and innovation
Language of Instruction	English
Coordinator	Benjamin Molina

Table 59. General info for the course 'Green Skills for Beyond 5G Technologies'

Note about the Total Learning Hours and Required Effort

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The **20 hours of lectures** are delivered through a mix of **concise, pre-recorded videos**, **interactive presentations**, and **expert-led content** that target core knowledge areas in **sustainability** and **5G technology**. Each lecture session is designed to focus on specific **learning outcomes** and is supplemented with **brief comprehension tasks** to reinforce learning without exceeding the time budget. The balance between videos, readings, short knowledge checks, and applied tasks should be made more explicit from the start of the course.

The **15 hours of practical exercises** include **applied simulations**, **design activities**, **case-based analysis**, and **collaborative group work** conducted online. These activities are carefully calibrated in **complexity and scope** to remain within the allocated time while enabling **skill development** and **practical engagement** with sustainability analysis, design, and decision-making in telecom networks. The **depth of both content and exercises** is intentionally adjusted to reflect the total course hours, ensuring that learners are not overburdened and that expectations remain aligned with the 2 ECTS credit allocation. Where appropriate, short, guided examples should be used to prepare learners for more independent applied work.

The **independent study component** is tentatively distributed as follows:

- **12 hours** for reading, video-based learning, and topic review
- **3 hours** for completing **quizzes and MCQs** through the LMS
- **6 hours** to prepare and submit a **final assignment** (written or recorded)
- **4 hours** dedicated to **self-evaluation** using a structured checklist aligned with the course learning outcomes, encouraging students to reflect on their knowledge and skills before completing the course

These indicative allocations should be communicated clearly to learners so that expected effort remains transparent and proportionate to the 2 ECTS format.

The time allocated for **MCQs and quizzes** is considered part of the **independent stthe udy workload**, as these tasks are completed individually through the Learning Management System (**LMS**), without the need for instructor-led facilitation. They are designed as **self-paced knowledge checks** that support **formative learning** and help students reinforce their understanding of key concepts between lectures and practical sessions. This distinction ensures that the independent learning hours are fully utilised while maintaining a **manageable grading load**. Inthe refined version, tIn thequizzes should remain manageable and clearly distinguished from larger assignment-based tasks.

In contrast, the **practical exercises** represent **structured, instructor-guided** learning experiences that require deeper engagement. These activities include working with **energy efficiency simulations**, applying **design tools** to network optimisation scenarios, analysing real-world **sustainability case studies**, and participating in **collaborative planning tasks**. These exercises are aligned with the **skill-building objectives** of the course and are deliberately scoped to ensure **meaningful outcomes within the allocated time**. For substantial applied tasks, learners should also receive concise written briefs indicating the objective, expected steps, deliverables, and indicative time commitment.

This **balanced design** across lectures, exercises, and self-directed study ensures that the total workload remains **realistic, meaningful, and achievable** within the **60-hour frame** defined by the **2 ECTS credit allocation**. The refined implementation should preserve this specialist course identity while making the learner journey lighter, clearer, and more practice-ready

To further support ECTS alignment, the table below maps each major course activity to its estimated time allocation and the targeted levels of cognitive complexity, following **Bloom's Taxonomy**. This ensures that the overall 60-hour effort corresponds not only to quantity, but also to appropriate depth and progression of learning.

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Learning Component	Hours	Bloom's Level(s) Targeted
Lectures	20	**Remember**, **Understand**
Practical Exercises	15	**Apply**, **Analyse**
Quizzes & MCQs	3	**Understand**, **Apply**
Final Assignment	6	**Analyse**, **Evaluate**, **Create**
Reading & Topic Review	12	**Understand**, **Apply**
Self-Evaluation Checklist	4	**Evaluate**, **Reflect** (metacognition)
Total	**60**	–

Table 60. Time Allocation by Learning Component and Associated Bloom's Taxonomy Levels for the course 'Green Skills for Beyond 5G Technologies'

Course Description

The course *Green Skills for Beyond 5G Technologies* explores the integration of **environmental responsibility**, **green innovation**, and **digital transformation** within the next generation of telecommunications. It emphasises how **circular economy**, **life cycle thinking**, and **policy frameworks** can shape sustainable practices in designing, deploying, and managing 5G networks and digital infrastructure.

Rooted in the **Knowledge Skills Abilities (KSA) methodology**, the course fosters active, applied learning and the development of transversal competencies. It also aligns with the core values of the **Erasmus+ programme**, promoting **interdisciplinary learning**, **entrepreneurship**, **sustainability**, and **cross-sectoral collaboration**.

Learners will learn to understand and act on the environmental and societal implications of advanced 5G technologies while developing competencies in **green business models**, **regulatory analysis**, and **ethical innovation**.

The course is structured around four thematic modules:

- **Module 1:** Sustainable Design and Principles in 5G.
- **Module 2:** Circular Economy and Life Cycle Thinking in information and communication technologies (ICT).
- **Module 3:** Energy Efficiency and Carbon Reduction Strategies.
- **Module 4:** Regulatory, Ethical, and Business Perspectives on Green 5G.

In its refined form, the course preserves its specialist sustainability-oriented identity, but its implementation is made lighter, clearer, and more practice-ready. The revised version gives greater emphasis to guided applied understanding, improved navigation across materials, and a more coherent balance between conceptual depth and learner workload.

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Detailed Learning objectives (instructor-oriented)

Module	Learning Objectives
1. Sustainable Design and Principles in 5G	Enable students to: • Understand the fundamental principles of **green ICT** and their relevance in 5G network architecture. • Explore **emerging technologies** that contribute to more environmentally responsible communication systems. • Analyse the potential of **AI and automation** in supporting sustainability goals in telecom infrastructure. • Identify and apply **sustainable design strategies** for 5G networks, including data centres and cloud systems.
2. Circular Economy and Life Cycle Thinking in ICT	Enable students to: • Conduct and interpret a **life cycle assessment (LCA)** for ICT equipment and network components. • Describe and contextualise the application of **circular economy** principles in the digital and telecom sectors. • Evaluate ICT products and systems for **reusability, recyclability**, and modular design, as well as their implications for circularity-oriented design and procurement decisions. • Integrate **end-of-life planning** and sustainable sourcing into technology development workflows and broader sustainability-oriented design choices.
3. Energy Efficiency and Carbon Reduction Strategies	Enable students to: • Identify the main sources of **energy consumption** across the 5G network stack. • Apply practical strategies for **optimising energy performance** in 5G network planning and operations with particular attention to operational efficiency and environmental performance. • Use relevant tools to **monitor telecom deployments' carbon emissions and environmental indicators** and interpret sustainability metrics for decision-making. • Compare and assess different **carbon reduction approaches** in the context of diverse deployment models and operational scenarios.
4. Regulatory, Ethical, and Business Perspectives on Green 5G	Enable students to: • Navigate and interpret key **regulations, standards, and policy frameworks** for sustainable ICT. • Analyse **ethical considerations** in green innovation and the deployment of emerging technologies.

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	• Understand the relationship between **green strategy and business viability** in the telecom sector, including the implications of sustainability requirements for organisational decision-making. • Critically examine policy advocacy and corporate responsibility models in support of the digital-green transition, and relate them to compliance, stakeholder expectations, and practical implementation choices.
Cross-cutting Abilities (Soft Competencies, applicable to the 4 previous modules)	Enable students to: • Collaborate effectively in **multidisciplinary teams** and contribute to shared problem-solving. • Communicate ideas and solutions clearly through **presentations, debates**, and written outputs, including sustainability-oriented analyses and recommendations. • Think critically about the **societal and environmental implications** of digital technologies. • Cultivate an **entrepreneurial mindset** in addressing sustainability challenges in ICT.

Table 61. Learning objectives for the course 'Green Skills for Beyond 5G Technologies'

Detailed Learning Outcomes (student-oriented)

By the end of this course, students will be able to:

Module	Learning Outcomes
1. Sustainable Design and Principles in 5G	1. **Understand** the fundamentals of sustainable ICT systems and green 5G networks 2. **Describe** eco-design principles for 5G infrastructure and components 3. **Identify** emerging green technologies relevant to 5G deployment **Evaluate** the integration of sustainability into 5G system architecture
2. Circular Economy and Life Cycle Thinking in ICT	4. **Apply** circular economy principles to 5G and ICT systems 5. **Conduct and interpret** a life cycle assessment (LCA) for ICT components 6. **Understand** the use of sustainable materials and circularity-related design choices in network equipment

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	7. **Design** for reuse, recyclability, and end-of-life strategies in telecom systems, including their implications for procurement and sustainability planning
3. Energy Efficiency and Carbon Reduction Strategies	8. **Analyse** energy consumption in 5G networks 9. **Implement** energy-saving and carbon reduction techniques in telecom infrastructure 10. **Monitor** and optimise energy use across 5G components using relevant sustainability indicators and performance metrics 11. **Evaluate** the carbon footprint of 5G network deployments and compare improvement options across deployment scenarios
4. Regulatory, Ethical, and Business Perspectives on Green 5G	12. **Understand** sustainability-related regulations and standards for telecom systems 13. **Analyse** ethical considerations in sustainable technology deployment 14. **Evaluate** business strategies aligned with environmental goals and organisational sustainability requirements **15. Align** green initiatives with policy, regulatory, and stakeholder expectations in realistic telecom and digital-infrastructure contexts

Table 62. Learning outcomes for the course 'Green Skills for Beyond 5G Technologies'

The alignment between modules and KSA items is presented in the table below.

Module	Knowledge (General Competencies)	Skills (Specific Competencies)	Abilities (Soft Competencies)
1. Sustainable Design and Principles in 5G	**Fundamental principles of Green ICT and sustainability in telecommunications** Understand sustainability in ICT and eco-design **Emerging technologies for sustainable networks and communication systems** Innovations for energy-aware telecom	**Design sustainable telecom solutions and green ICT innovations** Integrating sustainability in design choices **Integration of AI and automation in sustainable network management** Using intelligent systems for	**Design and implement energy-efficient network infrastructures** Reduce emissions and operational costs **Innovate and develop next-generation sustainable ICT solutions** Promote green R&D and adoption

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	Sustainable data centres and energy-efficient cloud computing – Optimization strategies for green cloud systems	energy optimisation	
2. Circular Economy and Life Cycle Thinking in ICT	**Life cycle assessment (LCA) of ICT equipment and network sustainability** Assess full lifecycle environmental impact **Circular economy principles applied to ICT and green networks** Promote reuse, recycling, and sustainability loops **Circularity indicators, material-use assessment, and end-of-life performance in ICT systems** Track circularity-related metrics for sustainable design, procurement, and recovery planning **Sustainable materials, sourcing strategies, and environmental trade-offs in ICT value chains** Understand how material choices and sourcing decisions affect long-term sustainability performance	**Apply circular economy strategies in ICT operations** Reuse, recycling, and sustainable supply chain **Conduct and interpret life cycle assessment for ICT components and network equipment** Analyse environmental impact data across the product and system lifecycle **Use circularity and sustainability indicators to support procurement and design decisions** Track performance data relevant to reuse, recyclability, sourcing, and end-of-life planning **Analyse LCA and circularity data for continuous improvement** Identify opportunities to improve environmental performance	**Integrate sustainability practices into ICT business models** Link circularity with business value **Incorporate life cycle thinking into design and procurement choices** Justify sustainability-oriented decisions in realistic ICT and telecom scenarios **Promote responsible use of materials and resources in ICT systems** Align operational choices with circular economy goals **Support cross-functional sustainability planning in digital infrastructure contexts** Connect environmental analysis with organisational and strategic decision-making

		across ICT operations and value chains	
3. Energy Efficiency and Carbon Reduction Strategies	**Energy impact of telecommunications networks and energy-saving solutions** Quantify and reduce energy use **Green network optimisation techniques and sustainable telecom strategies** Apply efficient resource allocation **Carbon footprint, emissions sources, and environmental performance of ICT networks** Understand how telecom systems generate emissions and consume energy and resources **Monitoring and reporting of energy, carbon, and sustainability indicators in telecom operations** Track KPIs and performance data for optimisation and environmental improvement	**Implement energy-saving techniques in network management** Energy-efficient algorithms and architectures **Assess and mitigate the environmental impact of ICT solutions** Impact modelling and mitigation planning **Monitor and optimise energy use across telecom systems** Analyse operational data to identify efficiency opportunities and reduce emissions **Use carbon and sustainability metrics to evaluate network performance** Interpret performance indicators and compare alternative improvement strategies	**Lead and advocate for sustainability in ICT organisations** Champion green initiatives internally **Apply energy-efficiency principles in operational and planning decisions** Support more sustainable network deployment and management choices **Promote carbon-reduction strategies in telecom environments** Translate environmental targets into practical technical actions **Drive continuous improvement through sustainability monitoring and optimisation** Encourage evidence-based environmental decision-making in ICT operations

4. Regulatory, Ethical, and Business Perspectives on Green 5G	**Regulations and international standards for sustainable ICT and networks** Compliance with ESG/ITU/ISO standards **Economic Impacts of Sustainability Initiatives in ICT** Analyse cost-benefit and business alignment with green goals	**Understand and apply international sustainability standards** Apply ESG/ISO frameworks in 5G settings **Collaborative Practices for Sustainability in ICT** Work across teams and sectors for shared goals	**Analyse and comply with sustainability regulations** Ensure alignment with EU and global norms **Policy Advocacy for Sustainable ICT** Promote regulatory support for green digital transitions

Table 63. Alignment between KSA items and modules for the course 'Green Skills for Beyond 5G Technologies'

4.7.5. Detailed Modules and Units

MODULE	**Module 1:** Sustainable Design and Principles in 5G
UNIT	**Unit 1: Foundations of Green ICT and Emerging Sustainable Technologies**
Learning Hours	8 hours
Learning Outcomes	By the end of this unit, students will be able to: • Explain sustainability principles in the ICT context • Describe emerging technologies that support green 5G solutions • Assess the role of data centres in sustainable digital infrastructure
Teaching methods	Lectures, Case studies, Interactive simulations and short guided examples to support applied understanding
Assessment methods	Contributes to the module-level quiz and sustainability case analysis for the final assignment. No separate submission required. In the refined version, this contribution should remain formative and clearly signposted within the overall module pathway
Prerequisites	None
UNIT	**Unit 2: Eco-Design in 5G Networks and Cloud**

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Learning Hours	7 hours
Learning Outcomes	By the end of this unit, students will be able to: • Identify key eco-design strategies in telecom systems • Apply AI and automation for green network design • Evaluate energy-efficient architectures in cloud computing
Teaching methods	Hands-on lab, lectures, and guided design-oriented examples
Assessment methods	Activities support the final assignment. Key elements may be reused in the group presentation or design proposal. No separate lab report submission required. Where appropriate, learners should receive a short-written brief clarifying expected steps, outputs, and indicative effort.
Prerequisites	Unit 1 of Module 1

Table 64. Module 1 for the course 'Green Skills for Beyond 5G Technologies'

MODULE	**Module 2:** Circular Economy and Life Cycle Thinking in ICT
UNIT	**Unit 1: Life Cycle Assessment (LCA) in ICT**
Learning Hours	8 hours
Learning Outcomes	By the end of this unit, students will be able to: • Perform basic LCA on network equipment • Interpret environmental impact data over the ICT product life cycle • Assess sustainability trade-offs in ICT procurement
Teaching methods	Lectures, Practical exercises, LCA tool demonstration, and guided examples for interpreting LCA results.
Assessment methods	LCA findings are applied in a comparative analysis task. The practical work is formative; no separate project submission is required. A concise written brief should clarify the task objective, expected steps, deliverables, and indicative time commitment.
Prerequisites	None
UNIT	**Unit 2: Circular Economy Strategies in Green Networks**
Learning Hours	7 hours
Learning Outcomes	By the end of this unit, students will be able to:

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	• Explain circular economy principles in the telecom sector • Design for recyclability and modular reuse • Apply circularity-oriented assessment and decision-making tools for sustainable network practices
Teaching methods	Lectures, Scenario-based learning, Design thinking, and guided examples focused on reuse, modularity, sourcing, and end-of-life choices
Assessment methods	Students develop a circular economy strategy proposal (approx. 300 words) that contributes 20% toward the final assignment. A 10-question multiple-choice quiz at the end of the unit accounts for 10% of the overall module grade. In the refined version, this assessment should be streamlined so that the unit contributes to a clearer module-level pathway, avoiding unnecessary fragmentation and keeping the workload proportionate to the course scope.
Prerequisites	Unit 1 of Module 2.

Table 65. Module 2 for the course 'Green Skills for Beyond 5G Technologies'

MODULE	**Module 3:** Energy Efficiency and Carbon Reduction Strategies
UNIT	**Unit 1: Energy Consumption in 5G and Optimisation Techniques**
Learning Hours	8 hours
Learning Outcomes	By the end of this unit, students will be able to: • Identify energy-intensive components in 5G networks • Apply network-level power management strategies • Analyse energy profiles across different deployment models
Teaching methods	Lectures, Energy simulation tools, Hands-on demo, and short worked examples linked to operational optimisation
Assessment methods	Simulation-based optimization tasks completed during the unit contribute approximately 25% toward the final assignment. A 10-question multiple-choice quiz is included in the module-level assessment and contributes 10% to the overall module grade. In the refined version, assessment should place greater emphasis on guided application and should avoid over-fragmentation between small-graded items and larger tasks.
Prerequisites	None
UNIT	**Unit 2: Carbon Footprint Monitoring and Reduction in Telecom**
Learning Hours	7 hours

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Learning Outcomes	By the end of this unit, students will be able to: • Estimate the carbon footprint of a telecom deployment • Implement strategies to reduce emissions and resource use • Propose improvements based on sustainability KPIs and environmental performance indicators
Teaching methods	Data analysis exercises, Group work, and guided interpretation of carbon and sustainability metrics
Assessment methods	Team project and presentation feed into the final assignment. The executive summary is optional and may be used as part of the final deliverable. Because this unit is closely tied to monitoring and performance evaluation, task expectations should be made especially explicit through concise written instructions and clearly bounded deliverables.
Prerequisites	Unit 1 of Module 3

Table 66. Module 3 for the course 'Green Skills for Beyond 5G Technologies'

MODULE	**Module 4: Regulatory, Ethical, and Business Perspectives on Green 5G**
UNIT	**Unit 1: Regulations, Standards, and Ethics in Green ICT**
Learning Hours	8 hours
Learning Outcomes	By the end of this unit, students will be able to: • Identify key sustainability standards and frameworks in telecom • Evaluate compliance requirements for 5G systems • Discuss the ethical implications of sustainability in tech
Teaching methods	Lectures, Case-based discussion, Policy analysis, and short guided interpretation activities
Assessment methods	This unit should contribute to the module-level policy and ethics activity without requiring an unnecessarily separate assessment layer. Where applicable, outputs may inform the final assignment
Prerequisites	None
UNIT	**Unit 2: Business Models and Policy Advocacy for Sustainable 5G**
Learning Hours	7 hours
Learning Outcomes	By the end of this unit, students will be able to: • Design business models aligned with green telecom values

	• Promote ICT policy advocacy for green transitions • Analyse the cost-benefit of green initiatives in telecom
Teaching methods	Lectures, Case studies, Business model exercises, policy-note templates, and guided examples
Assessment methods	This unit should contribute to the final integrative assignment through a concise business and policy task. Because this unit was experienced as relatively demanding in the pilot implementation, instructions, expected outputs, and indicative effort should be especially explicit.
Prerequisites	Unit 1 of Module 4

Table 67. Module 4 for the course 'Green Skills for Beyond 5G Technologies'

Learning and Teaching Methods

This course adopts a blended, experience-based teaching approach to help students develop both foundational knowledge and practical competencies related to green transitions in the 5G and ICT sectors. The teaching methods combine conceptual instruction with project-based learning, reflective activities, and applied technical work, supported by clearer scaffolding, stronger orientation, and a more practice-ready progression through the course.

Key learning strategies include:

- **Project-Based Learning (PBL):** Students engage with real-world sustainability challenges in the ICT sector. These projects may involve evaluating the lifecycle of network components, proposing circular economy solutions, or simulating greener deployment models for 5G systems. In the refined version, project-based activities are supported by clearer progression from introductory explanations to more independent applied work.
- **Case-Based Learning:** Selected case studies (covering regulatory policy, green business strategies, and ethical dilemmas in digital infrastructure) allow students to connect theoretical concepts to concrete, real-world contexts. These case-based activities remain central to the course but should be accompanied by clearer practical anchors and stronger links between conceptual content and applied expectations.
- **Hands-on Technical Work:** Through guided exercises and virtual labs, learners apply tools such as life cycle assessment software, sustainability metrics, and energy monitoring frameworks relevant to telecom systems. In the refined version, this practical work is supported through short, guided examples and clearer step-by-step demonstrations, especially for topics such as LCA interpretation, sustainability indicators, energy and emissions metrics, eco-design trade-offs, and business or regulatory analysis.
- **Interactive Lectures:** Lectures are designed to be participatory, combining expert input with Q&A, student feedback, and group discussion around key topics like sustainable design principles, policy frameworks, and circular thinking. Presentation materials should also be revised to reduce text density, improve visual hierarchy, and incorporate short synthesis or key-takeaway elements that support attention and retention.
- **Independent Learning:** Students are encouraged to deepen their understanding through assigned readings, curated resources, and reflective tasks. Independent study

supports self-paced learning and helps students connect course content to their academic or professional interests. In the refined version, independent learning is supported by a clearer landing-page roadmap, better grouping of materials, short unit-level summaries, and a more consistent use of readings, useful links, and concise supporting resources across units

This integrated approach ensures that students gain **practical green skills**, develop **critical awareness of the sustainability landscape**, and can **bridge the gap between digital innovation and environmental responsibility**. The refined implementation preserves this analytical depth while making the learner journey lighter, clearer, and more practice-ready.

Work-Based Learning

Work-based learning (WBL) in this course bridges theory and practice by placing students in professional scenarios drawn from real challenges in digital and green transitions. It offers a structured environment where learners can apply knowledge to problems typically faced in sustainability-oriented telecom, policy, or engineering roles. In the refined version, these applied scenarios are introduced with clearer practical framing and stronger guidance on expected outputs, so that learners can engage with them more confidently and efficiently.

Students will gain practical exposure through:

- **Scenario-based simulations**, such as conducting a life cycle assessment of 5G equipment or designing an energy-conscious upgrade plan for a telecom operator. These simulations should remain central, but where appropriate, they should be preceded by short, guided examples showing how key concepts are operationalized step by step.
- **Applied data analysis** tasks using sustainability KPIs, allowing learners to interpret and act upon real-world environmental metrics from digital systems. In the refined version, the definitions and use of sustainability indicators should be made more explicit, especially where learners are asked to interpret metrics related to circularity, energy, or carbon performance.
- **Design challenges** where students prototype circular business models, policy briefs, or eco-design concepts aligned with EU goals. These tasks should be supported through concise written assignment briefs indicating the objective, expected steps, required deliverables, evaluation criteria, and indicative time commitment.
- **Team-based projects** that mimic collaborative environments found in industry, consulting, or research settings in the ICT and sustainability sectors. These projects continue to reflect the interdisciplinary and professional orientation of the course, while the refined version should ensure that templates, checklists, or brief support materials are available where needed before learners complete the tasks independently.

These activities are embedded within the course structure and do not require placement in external workplaces. However, when institutional conditions permit, students may be encouraged to pursue **industry collaborations, field projects, or internships** to reinforce learning with hands-on experience in real operational settings.

This work-based dimension is also fully aligned with the project’s broader PBL approach, where realistic tasks and case studies are intended to account for a substantial part of the learning experience and to connect academic content with professional practice. In the case of this course, WBL should therefore be understood not as an optional add-on, but as a core

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mechanism for translating sustainability concepts into realistic design, evaluation, compliance, and policy-oriented action.

Through work-based learning, students will build a portfolio of skills, tools, and project experiences that reflect **green competence**, **interdisciplinary problem-solving**, and **a readiness to contribute to sustainability efforts in the digital economy**. The refined implementation preserves this applied orientation while making the learner pathway clearer, better scaffolded, and more proportionate to the 2 ECTS course format.

*Note: While digital tools support many of these activities, this section focuses on the **professional tasks and scenarios** learners engage with rather than the technologies, which are detailed in Section 8*.

Digital Competencies

This course empowers learners to develop advanced digital competencies tailored to the sustainability challenges of next-generation telecommunications. Students build the technical foundation necessary to engage in data-driven, ethical, and green innovation by working with contemporary tools and digital environments. In the refined version, these digital competencies are supported through clearer practical guidance, more explicit links between tools and tasks, and stronger scaffolding for applied interpretation and decision-making

Key digital skill areas include:

- **Life Cycle and Environmental Impact Tools:** Learners will use software platforms that support life cycle assessment (LCA), estimation of carbon footprint, and sustainability reporting in ICT contexts. Where relevant, this may include tools and frameworks such as OpenLCA, Product Environmental Footprint (PEF) approaches, and related environmental-impact resources used in the project's case-study ecosystem.
- **Data Monitoring and Visualisation:** Students will explore tools for tracking environmental performance indicators, such as energy consumption, emissions, or circularity metrics within 5G networks and related infrastructure. In the refined version, the meaning and practical use of these indicators are made more explicit through short, guided examples and better alignment with module activities.
- **Simulation and Modelling Environments:** Learners will work with digital environments for simulating 5G deployment scenarios, network behaviour, and energy optimisation strategies. Depending on the implementation context, this may include simulation and analysis tools such as ns-3, RETScreen, HOMER, or comparable environments relevant to sustainability-oriented telecom analysis
- **Policy and Standards Mapping Tools:** The course introduces platforms and frameworks that help students interpret and align ICT practices with international sustainability standards (e.g., ESG, ISO, ITU), as well as regulatory and policy references relevant to green digital transitions.
- **Collaborative Digital Platforms:** Throughout the course, students will use cloud-based tools for team communication, project development, and knowledge sharing, mirroring professional collaboration practices in the green tech space. In the refined version, these collaborative environments support clearer task navigation, access to supporting resources, and better visibility of expected outputs.

By the end of the course, students will not only understand sustainability principles conceptually but will also be equipped to apply them using a digital toolkit grounded in **measurement**, **analysis**, and **strategic decision-making**. The refined implementation makes this toolkit more

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visible and more usable by connecting digital tools more systematically to case studies, guided exercises, and clearly signposted assignments.

Assessment and Feedback Mechanism

The assessment strategy in this course is designed to evaluate students' understanding of green concepts, their ability to apply sustainability principles in telecom contexts, and their engagement with interdisciplinary problem-solving. Assessments are aligned with both the **modular learning outcomes** and the **KSA-based structure** of the course. In the refined implementation, the distinction between formative checks, scaffolded applied tasks, and the main summative deliverable is made more visible from the start of the course.

Assessment Streamlining and Alignment

To ensure the total workload stays within the 2 ECTS (60-hour) limit, the course has adopted a streamlined approach to assessment. Unit-level tasks such as quizzes, short essays, or project fragments have been consolidated into **module-level assessments**. A **single final deliverable**, such as a sustainability plan, policy proposal, or audit simulation, serves as the primary summative evaluation. Where substantial tasks are required, concise written briefs should also be provided, indicating the objective, expected steps, required outputs, evaluation criteria, and indicative time commitment.

This ensures that students engage regularly with content while avoiding overload from excessive standalone submissions. Formative tasks help scaffold toward the final assignment, while automated tools and collaborative formats reduce administrative overhead. In the refined version, this scaffolded progression remains explicit at the module level, so that learners can clearly understand how smaller activities support the final assignment.

A range of assessment formats is used to capture different dimensions of learning:

- **Multiple-choice Questions (MCQs):** Assess foundational knowledge of green ICT principles, sustainability standards, and policy frameworks. MCQs provide quick feedback and support knowledge retention. These should remain low-stakes and formative.
- **Short Answer Questions:** Allow students to articulate key sustainability concepts, explain methodologies such as LCA, or interpret regulatory frameworks concisely.
- **Design and Problem-Solving Tasks:** Students may be asked to propose solutions to real-world sustainability challenges in ICT, such as reducing environmental impact, improving circularity, or aligning a business model with green principles. These tasks should preferably function as guided steps toward the final integrative deliverable rather than as a large number of separate graded submissions.
- **Essays and Brief Reports:** Enable deeper critical reflection on thematic topics, such as the role of policy in shaping sustainable telecom or the ethical tensions in digital transformation. Where used, they should remain proportionate to the 2 ECTS workload.
- **Projects and Presentations:** Used to assess applied competencies in cross-cutting tasks, such as designing a sustainability strategy for a 5G rollout or evaluating a telecom company's environmental reporting. These are often team-based and simulate real stakeholder engagement. Presentation-based tasks should support, rather than duplicate, the main final assignment.

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- **Case Study Analyses:** Assess students' ability to understand and respond to complex scenarios drawn from industry, policy, or research practice, linking theory to practice. These activities should be supported by clear instructions and bounded expectations.

Feedback is both formative and summative and includes:

- **Automated feedback** for MCQs and quizzes, enabling students to assess their progress instantly.
- **Written feedback** on assignments and reports, focusing on clarity, critical depth, and alignment with sustainability goals.
- **Peer** and **collaborative feedback** where group-based tasks are used, supported by simple criteria or review prompts.
- **Self-reflection elements**, where appropriate, to help students recognize their progress and consolidate learning.

This multi-modal assessment system ensures that students are not only evaluated on their retention of knowledge but also on their **ability to analyse**, **create**, and **communicate** sustainability solutions within digital contexts.

Estimated Time Per Assessment Type

Indicative workload expectations should also be communicated transparently to learners. A reasonable guide is:

- **Module-level quizzes**: ~30-45 minutes each
- **Short written tasks**: ~1.5-2 hours
- **Final integrative assignment**: ~6 hours total

This helps maintain alignment with the total 60-hour workload and reinforces the course's streamlined assessment design.

The final deliverable may tentatively take the form of a capstone-style simulation or integrative applied task, such as a sustainability audit plan, circularity strategy, deployment proposal, or policy-and-business recommendation for a hypothetical telecom operator or related stakeholder. This assignment is designed to mirror real-world roles and tasks and to connect design, circularity, environmental performance, regulation, and business reasoning in a single applied scenario.

Recommended readings

The following readings are recommended to support learning in each module. These resources include foundational overviews, applied research, and state-of-the-art surveys relevant to Beyond 5G (B5G) technologies. The course platform will provide links to open-access versions or institutional library access where available. In the refined version, supporting resources are distributed more consistently across units, and each unit includes, where appropriate, further readings, useful links, and short key takeaways to support orientation and self-paced study.

Module 1: Sustainable Design and Principles in 5G

- **"5G and Sustainability: The Role of Green 5G in the Energy Transition"**
  STL Partners, 2024.

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This article explores how 5G networks contribute to energy efficiency and support the global energy transition towards sustainability.
https://stlpartners.com/articles/sustainability/5g-and-sustainability/

- **"Energy Efficiency and Sustainability in Mobile Communications Networks"**
  5G Americas, 2024.
  This white paper provides an in-depth analysis of strategies and technologies essential for the energy-efficient operation of mobile networks.
  https://www.5gamericas.org/energy-efficiency-and-sustainability-in-mobile-communications-networks/

- ***The Energy Demand of Data Centers*** in **"ICT innovations for sustainability"**
  Hilty, Springer, 2015
  This book chapter explores how the growing demand for cloud services and web applications drives energy consumption in data centres, emphasizing the importance of selecting optimal components and architectures to balance energy efficiency, availability, and performance, while highlighting key influencing factors, current trends, and practical examples.
  https://link.springer.com/content/pdf/10.1007/978-3-319-09228-7.pdf

Module 2: Circular Economy and Life Cycle Thinking in ICT

- **"Creating a Circular Economy for Electronic and Electrical Equipment"**
  International Telecommunication Union (ITU), 2024.
  This backgrounder discusses the importance of responsible innovation and circular economy principles in the lifecycle of digital technologies.
  https://www.itu.int/en/mediacentre/backgrounders/Pages/e-waste.aspx

- **"Integrating Circularity in ICT's Net Zero Transition"**
  The Carbon Trust, 2024.
  This insightful article examines how circular economy initiatives can be integrated into the ICT sector's transition to net-zero emissions.
  https://www.carbontrust.com/news-and-insights/insights/integrating-circularity-in-icts-net-zero-transition

- **"Circular Economy in the ICT Sector: Call for a More Comprehensive European Approach"**
  The European Files, 2024.
  This article advocates for a comprehensive European approach to implementing circular economy principles within the ICT sector.
  https://www.europeanfiles.eu/digital/circular-economy-in-the-ict-sector-call-for-a-more-comprehensive-european-approach

- **"Building a Digital Circular Economy"**
  UK Research and Innovation (UKRI), 2024.
  This blog post discusses the potential of digital technologies to accelerate efforts towards a circular economy and increased environmental sustainability.
  https://www.ukri.org/blog/building-a-digital-circular-economy/

Module 3: Energy Efficiency and Carbon Reduction Strategies

- ***Energy-efficient transmission*** in **"Energy and Spectrum Efficient Wireless Network Design"**.
  Miao G, Cambridge University Press, 2014
  This book chapter introduces the concept of energy efficiency capacity, i.e. the highest

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energy efficiency a wireless link can achieve, and the corresponding optimal designs for point-to-point link communications across time, frequency, and spatial domains.
https://www.cambridge.org/core/services/aop-cambridge-core/content/view/2AC0F55BCBCDB7AB189BDC133741974C/9781139626774c19_p244-281_CBO.pdf/energyefficient_transmission.pdf

- **"5G: Climate Action and Mitigating Environmental Risks"**
  Ericsson, 2024.
  This article discusses how 5G technology can enable energy savings and reduce carbon emissions, contributing to climate action efforts.
  https://www.ericsson.com/en/blog/middle-east-africa/2024/5g-a-silver-lining-for-accelerating-climate-action-and-mitigating-environmental-risks
- **"Net Zero Target: A Greener Future with 5G"**
  Ericsson, 2024.
  This analysis explores how 5G technology can directly reduce fossil fuel emissions and support sustainability across various industries.
  https://www.ericsson.com/en/about-us/company-facts/ericsson-worldwide/united-kingdom/uk-analysis-mason-report/a-greener-future

Module 4: Regulatory, Ethical, and Business Perspectives on Green 5G

- **"5G and Government: A Regulatory Roadmap"**
  Wiley Rein LLP, 2024.
  This comprehensive guide examines the regulatory landscape of 5G deployment, discussing policy considerations, compliance challenges, and the role of government in facilitating sustainable 5G infrastructure.
  https://www.wiley.law/media/handbook/550_2021-Wiley-5G-Roadmap.pdf
- **"Regulation and Innovation in 5G Markets"**
  Telecommunications Policy, 2021.
  This article analyses how different regulatory approaches impact innovation in 5G markets, emphasising the balance between regulation and promoting sustainable technological advancements.
  https://www.sciencedirect.com/science/article/pii/S0308596121001646
- **"5G and Human Rights: What's the Connection?"**
  Ericsson Blog, 2021.
  This piece explores the ethical considerations of 5G technology, discussing potential human rights implications and the importance of responsible deployment to ensure equitable access and privacy.
  https://www.ericsson.com/en/blog/2021/3/5g-human-rights
- **"Green is Good for Business: Embedding Sustainability in Digital Transformation"**
  Huawei, 2023.
  This white paper discusses how businesses can integrate sustainability into their digital transformation strategies, highlighting the role of 5G in achieving environmental goals and the associated regulatory considerations.
  https://carrier.huawei.com/~/media/cnbgv2/download/better-world/telco-sustainability-whitepaper.pdf
- **"5G Regulatory Policy and Assignment Strategies"**
  Coleago Consulting, 2023.
  This document provides insights into regulatory policies and spectrum assignment strategies for 5G, focusing on creating an environment that encourages investment

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while addressing sustainability concerns.
https://www.coleago.com/app/uploads/2018/03/5G-Regulatory-Policy-and-Assignment-Strategies.pdf

Where relevant, instructors may also complement the above readings with selected resources from the project's case-study ecosystem, especially materials related to LCA, sustainability KPIs, Green Deal / energy-efficiency policy references, circular procurement, and tool-oriented resources such as OpenLCA, PEF approaches, RETScreen, HOMER, ns-3, or GSMA / ITU sustainability references. These complementary resources should support the applied tasks without overloading the core reading pathway.

Development of Soft Skills

In addition to technical knowledge and applied sustainability practices, this course emphasises developing **soft skills** essential for 21st-century professionals working at the intersection of digital and green transitions. These competencies are woven throughout the course structure and are aligned with the **transversal abilities** identified in the KSA framework and with the course's cross-cutting emphasis on multidisciplinary collaboration, communication, critical thinking, and entrepreneurial initiative.

Key soft skills addressed in the course include:

- **Critical thinking and ethical reasoning**: Through case studies and discussions on regulation and policy, students examine the societal impact of emerging digital technologies and evaluate trade-offs in sustainability decisions.
- **Communication and collaboration**: Students engage in team-based activities such as sustainability project development, peer reviews, and policy advocacy simulations, enhancing their ability to collaborate and present ideas clearly in interdisciplinary settings.
- **Leadership and initiative**: Learners lead in proposing innovative green solutions, contributing to debates on sustainable telecom practices, and developing action plans grounded in real-world industry or policy contexts.
- **Adaptability and problem-solving**: Scenario-based exercises, such as designing circular business models or responding to regulatory shifts, strengthen students' capacity to respond flexibly and creatively to evolving challenges.
- **Entrepreneurial mindset**: Learners are encouraged to think beyond compliance and consider how sustainability can drive value creation, innovation, and strategic advantage in ICT-related sectors.

These soft skills are integrated into the **assessment process** via team projects, case-based activities, presentations, and feedback cycles. While not always evaluated as standalone competencies, they are key to students' overall performance and readiness for **professional roles in green, digital, and policy-driven environments**. In the refined version, their development is supported through clearer task briefs, more guided case work, and structured reflection opportunities that help learners connect technical analysis with communication, teamwork, and decision-making practice.

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Industry Collaboration and Internships

While this course is primarily developed as part of a research-driven Erasmus+ initiative focused on **online learning**, it is designed with a clear view of the **professional and industry contexts** in which green digital skills are increasingly relevant.

To encourage students' exposure to real-world applications of the course content, the following forms of **industry engagement are recommended**, though not formally integrated into the course delivery:

- **Guest lectures and expert panels**, particularly in asynchronous or recorded formats, can offer valuable perspectives from professionals in sustainability, telecom, or digital policy. These may be developed as supplemental resources or included when partnerships allow.
- **Case studies and problem-based scenarios** inspired by industry reports or policy initiatives help learners simulate challenges such as carbon reporting, sustainable infrastructure planning, or green compliance in telecom environments. In the refined version, these case-based activities continue to serve as the main bridge to professional practice, especially where direct industry participation is not available.
- **Independent student-led projects**, such as sustainability audits, green innovation proposals, or circular economy strategies for ICT systems, can be framed to reflect real professional challenges, even without direct industry involvement. Where appropriate, these projects may also draw on business-oriented, regulatory, or stakeholder-facing formats to strengthen their professional relevance.
- **Internships or mentorships**, where accessible through the learner's home institution or professional network, are encouraged to deepen experience and apply course knowledge in context. However, such activities fall outside the scope of this course's core offering. The refined version keeps this position explicit: internships may be encouraged, but they are not a required or embedded component of the course.

The course aims to prepare learners for professional roles in **green digital transitions**, even where direct exposure to industry environments is limited. By working with realistic challenges and exploring best practices across sectors, students build the awareness and competencies to engage meaningfully with sustainability goals in the telecom and ICT landscape. This applied orientation is also aligned with the wider 5G-DiGITs approach, which promotes case-based learning, project-based learning, networking, and collaboration with external stakeholders as complementary mechanisms for strengthening employability and industry relevance.

Accessibility and Inclusivity

While the primary focus of this course is to deliver **high-quality, research-based content** on green skills in the context of Beyond 5G technologies, efforts have been made to ensure that the course is **as accessible and inclusive as reasonably possible** within the project's scope.

The course is delivered online and designed to accommodate a range of learners and learning styles, with the following recommended features and good practices:

- **Transcripts are included** for all video content, supporting both non-native English speakers and learners with hearing impairments. Subtitles may also be provided where platform capabilities allow.
- **Modular, asynchronous delivery** allows students to access and complete content at their own pace, supporting flexibility and individual learning preferences.

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• **Clear, structured presentation** of materials supports comprehension and navigation, especially in self-paced learning environments, and promotes basic compatibility with screen-reading tools. In the refined version, this includes a clearer course landing-page roadmap, better grouping of materials, and short unit-level summaries to help learners navigate the course more easily.

• **Language support tools**, such as glossaries and definitions of technical terms, are provided to assist learners from various academic or professional backgrounds. Where relevant, concise supporting resources and useful links should also be presented more consistently across units to reduce disorientation and support self-paced study.

While a full range of accessibility adaptations (e.g., advanced screen reader testing, fully multilingual versions, or extensive alternative formats) is not guaranteed at this stage, the course design takes into account common barriers and aims to minimise them within project constraints. Learners may optionally use **third-party tools to translate core materials** into other languages if needed. For substantial assignments, accessibility and usability should also be supported through concise written task instructions that clearly explain the objective, expected steps, required outputs, and indicative effort.

The project team encourages institutions or instructors implementing this course to adapt it further to meet local or institutional accessibility standards when possible. The refined implementation preserves the current accessibility measures while improving learner orientation, navigation, and clarity of support materials throughout the course.

ECVET/ECTS Credit Allocation

The 60 learning hours are distributed across different types of activities:

- **Lectures and instructional content**: 20 hours
- **Practical exercises and guided activities**: 15 hours
- **Independent study, reading, and assessment preparation**: 25 hours

The distribution of ECTS credits across modules is based on the relative weight and expected workload of each:

- **Module 1: Sustainable Design and Principles in 5G** – *0.5 ECTS (15 hours)*
- **Module 2: Circular Economy and Life Cycle Thinking in ICT** – *0.5 ECTS (15 hours)*
- **Module 3: Energy Efficiency and Carbon Reduction Strategies** – *0.5 ECTS (15 hours)*
- **Module 4: Regulatory, Ethical, and Business Perspectives on Green 5G** – *0.5 ECTS (15 hours)*

This allocation reflects the expected time investment across **content acquisition, applied activities**, and **student-led learning**. In the refined version, this formal allocation remains unchanged, but the internal balance of learning effort is improved through clearer sequencing of activities, more proportionate assessment demands, and more transparent communication of expected workload across units and tasks.

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8. Entrepreneurial Skills for Beyond 5G Technologies

General Information

Course Title	Entrepreneurial Skills for Beyond 5G Technologies
DoA Learning Outcomes	• Develop an entrepreneurial mindset and leadership skills for the 5G sector. • Apply project management, communication, negotiation, and decision-making techniques. • Understand risk management principles and apply them to 5G business ventures.
EQF Level	5
ECVET/ECTS Credits	2 ECTS
Total Learning Hours	60 hours • 20 hours of lectures, • 15 hours of practical exercises • 25 hours of independent study
Audience	Undergraduate and graduate students in telecommunications, computer sciences, digital technologies, engineering, Business and management students with an interest in tech-driven innovation, Researchers and R&D teams, New entrepreneurs, spin-off and start-up Founders and Managers, TTOs, and Innovation officers in universities.
Prerequisites	Basic knowledge of 5G networks and telecommunications
Language of Instruction	English
Coordinator	Christina Skoubridou

Table 68. General info for the course 'Entrepreneurial Skills for Beyond 5G Technologies'

Course Description

This course is part of the 5G-DiGITs curriculum and aims to provide comprehensive knowledge, skills, and abilities (KSAs) in entrepreneurship for the Beyond 5G (B5G) technology ecosystem. The curriculum aligns with Erasmus+ requirements and the KSA methodology. It covers innovation techniques, leadership skills, business fundamentals, and practical entrepreneurship competencies for professionals in the 5G sector. The course's distinct value proposition is focusing on entrepreneurial soft skills beyond the technology itself.

The course follows an entrepreneurial journey, beginning with innovation methodologies that serve as the foundation for problem identification and solution development. These innovation skills then directly support leadership development and market opportunity recognition. The business fundamentals build on these insights to create viable venture models, culminating in resilience-building competencies essential for long-term entrepreneurial success in the dynamic 5G landscape.

The course is structured around four thematic modules:

- Module 1: Innovation & Creativity - establishing the foundation for entrepreneurial thinking and idea generation within the 5G context
- Module 2: Problem Solving & Leadership opportunities in the 5G market - applying innovation methodologies to identify market gaps and lead teams effectively
- Module 3: Business Fundamentals for 5G Ventures - transforming validated concepts into commercially viable business models
- Module 4: Building Resilience in Entrepreneurship - developing adaptability and risk management competencies for sustainable venture growth

Detailed Learning objectives (instructor-oriented)

Module	Learning Objectives
Module 1 **Innovation & Creativity**	• To teach students innovation methodologies such as Design Thinking, Creativity in 5G Design Driven Innovation, and Open Innovation. • To explain techniques for generating new ideas and thinking outside the box. • To demonstrate how to apply creative thinking to 5G business challenges. • To introduce the innovation ecosystem in the Beyond 5G technology sector.
Module 2 **Problem Solving & Leadership opportunities in the 5G market**	• To teach students methodologies for identifying challenges in the 5G market • To explain effective ways of leading a team, making decisions, and inspiring others. • To demonstrate successful leadership approaches in 5G start-ups. • To introduce principles of team management and conflict resolution.
Module 3 **Business Fundamentals for 5G Ventures**	• To teach students essential financial literacy for entrepreneurs • To explain budgeting, investments, and cash flow management. • To demonstrate marketing strategies and sales techniques for 5G technologies. • To introduce strategic thinking and long-term business planning.

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Module 4 **Building Resilience in Entrepreneurship**	• To teach students how to adapt to new situations and build resilience • To explain risk assessment and management frameworks for 5G Skills ventures • To demonstrate networking and partnership development techniques • To introduce time management and resource allocation methods.

Table 69. Learning objectives for the course 'Entrepreneurial Skills for Beyond 5G Technologies'

Detailed Learning Outcomes (student-oriented)

By the end of this course, students will be able to:

Module	Learning Outcomes
Module 1 **Innovation & Creativity**	• **Understand** Innovation and think creatively in 5G methodologies. • **Use** methodologies to generate new design thinking and new ideas, • **Adopt** Open Innovation frameworks for 5G approach problems • **Understand** the innovation business with innovative principles, challenges, and solutions.
Module 2 **Problem Solving & Leadership opportunities in the 5G market**	• **Acquire** leadership and managerial skills • **Identify** challenges and find effective solutions through problem-solving methods • **Understand** decision-making frameworks • **Organise** teams and implement effective management approaches.
Module 3 **Business Fundamentals for 5G Ventures**	• **Understand** Business budgeting, • **Adopt** Strategic thinking and Implement Marketing planning • **Design** Business financial plans • **Understand** the Fundamentals of running a 5G venture. • **Expand** their capabilities in projections, sales abilities, and investment value
Module 4 **Building Resilience in Entrepreneurship**	• **Perform** risk adaptability, • **Design** and implement risk management and assessment, • **Acquire** Networking Skills • **Apply** time management techniques

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	• **Acquire** the right feedback and integrate it effectively

Table 70. Learning outcomes for the course 'Entrepreneurial Skills for Beyond 5G Technologies'

The alignment between modules and KSA items is presented in the table below.

Module	Knowledge (General Competencies)	Skills (Specific Competencies)	Abilities (Soft Competencies)
Module 1 **Innovation & Creativity**	Understanding innovation methodologies	Applying creative thinking to generate ideas	Ability to think creatively, approach problems with innovative solutions
Module 2 **Problem Solving & Leadership opportunities in the 5G market**	Knowledge of problem-solving frameworks, leadership principles	Identifying challenges, conducting market research, and implementing solutions	Leadership, team management, decision-making
Module 3 **Business Fundamentals for 5G Ventures**	Understanding financial, investment & marketing principles	Creating budgets, projections, and value propositions	Strategic thinking, marketing acumen, and long-term planning
Module 4 **Building Resilience in Entrepreneurship**	Knowledge of risk management frameworks and networking techniques	Implementing risk assessment, managing time/resources	Adaptability, resilience, continuous learning, and networking

Table 71. Alignment KSA-modules for the course 'Entrepreneurial Skills for Beyond 5G Technologies'

Detailed Modules and Units

MODULE	**Module 1:** Innovation & Creativity
UNIT	**Design Thinking for 5G Innovation**
Learning Hours	8 hours
Learning Outcomes	Generating Innovative Ideas, Storytelling techniques,
Teaching methods	Lecture, Useful guides, Explanatory Tools & Templates, Case studies, Independent Study , Additional Textboooks and readings, Quizzes
Assessment methods	Case exercises, Innovation Challenge, Individual assessments. Group Projects
Prerequisites	None

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UNIT	**Open Innovation and 5G Ecosystem Collaboration**
Learning Hours	7 hours
Learning Outcomes	Apply creative thinking to 5G businesses' challenges
Teaching methods	Design Thinking Lectures, Useful guides, Explanatory Tools & Templates, Case studies, Brainstorming, Independent Study, Additional Textboooks and readings, Quizzes
Assessment methods	Designing Innovation Partnerships, Pitching, Case study analysis
Prerequisites	Unit 1 of Module 1

Table 72. Module 1 for the course 'Entrepreneurial Skills for Beyond 5G Technologies'

MODULE	**Module 2:** Problem Solving & Leadership opportunities in the 5G market
UNIT	**Structured Problem Solving for 5G Market Opportunities**
Learning Hours	8 hours
Learning Outcomes	Problem-solving methods
Teaching methods	Lecture, Case studies, Quizzes, Independent Study
Assessment methods	Problem Solving & Identification opportunities exercises, Reports
Prerequisites	None
UNIT	**Leadership and Team Management in Technical Ventures**
Learning Hours	7 hours
Learning Outcomes	Team leading, Human Management, Effective Decision making, Ethics in Decision making
Teaching methods	Leadership simulations, Role-playing, Quizzes, Independent Study
Assessment methods	Team Leadership exercise, Peer evaluation
Prerequisites	Unit 1 of Module 2

Table 73. Module 2 for the course 'Entrepreneurial Skills for Beyond 5G Technologies'

MODULE	**Module 3:** Business Fundamentals for 5G Ventures
UNIT	**Business Planning and Financial Strategies in 5G market**

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Learning Hours	8 hours
Learning Outcomes	Develop Financial & Business plans
Teaching methods	Lecture, Case studies, Guides, Quizzes, Explanatory Tools and Templates, Independent Study, Quizzes, Additional Readings
Assessment methods	Practical Financial Ventures exercises analysis, Business Canvas, Business Modeling
Prerequisites	None
UNIT	**Marketing and Go-to-Market Strategy**
Learning Hours	7 hours
Learning Outcomes	Creating Marketing strategies
Teaching methods	Principals & Framework Theory, Case Studies, Marketing planning, Go-To-Market Strategy, Policies & Reports, Quizzes,Independent Study
Assessment methods	Presentations, Value proposition design, Go-To Market Strategy
Prerequisites	Unit 1 of Module 3

Table 74. Module 3 for the course 'Entrepreneurial Skills for Beyond 5G Technologies'

MODULE	**Module 4:** Building Resilience in Entrepreneurship
UNIT	**Risk Assessment and Contingency Planning**
Learning Hours	8 hours
Learning Outcomes	Risk Assessment and Management
Teaching methods	Entrepreneurship & Resilience B5G ventures workshop, Case studies, independent study
Assessment methods	Reports, Generating Mitigation Strategies Exercises
Prerequisites	None
UNIT	**Networking and Resource Management**
Learning Hours	7 hours
Learning Outcomes	Network effectively and manage time and resources
Teaching methods	Networking exercises, lectures, and workshops
Assessment methods	Partnership proposal, time management plan, report

Prerequisites	Unit 1 of Module 4

Table 75. Module 4 for the course 'Entrepreneurial Skills for Beyond 5G Technologies'

Learning and Teaching Methods

The course employs a mix of traditional and innovative teaching methods to facilitate comprehensive learning:

- Problem-Based Learning (PBL) using real-world 5G market challenges
- Case Study Analysis of successful and failed telecommunications ventures
- Work-Based Learning through simulated startup environments
- Interactive Lectures with industry guest speakers
- Design Thinking Workshops using Miro and MURAL digital collaboration tools
- Role-Playing Exercises simulating investor pitches and customer discovery
- Team-Based Projects with defined roles and deliverables

Work-Based Learning

Work-based learning includes practical exercises and independent study, allowing learners to gain practical experience in 5G technologies.

- Development of a minimum viable product (MVP) for a B5G technology venture using rapid prototyping tools (e.g., Figma, InVision)
- Business plan creation for a 5G/B5G start-up concept using Lean Canvas and financial modelling templates
- Market analysis and opportunity identification exercises using structured frameworks (PESTEL, Porter's Five Forces)
- Risk assessment and mitigation planning for real-world scenarios using standardized risk matrix templates
- These practical components follow a continuous project approach where students develop a single venture concept throughout the course, applying new skills to the same project as they progress through the modules.

Digital Competencies

The course emphasises the development of the following digital skills:

- Digital tools for business planning and financial projections:
    - Lean Stack for business modelling
    - Excel/Google Sheets for financial projections
    - Trello for project management
- Online collaboration and project management platforms:
    - Miro for ideation and design thinking

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  - Slack for team communication
  - Monday.com for project tracking
- Market research and analysis using digital resources:
  - Google Trends for market analysis
  - Statista for industry data
  - Crunchbase for competitor research
- Digital presentation and pitching skills:
  - Pitch.com for deck creation
  - Loom for asynchronous pitching
  - Canva for visual communication

Assessment and Feedback Mechanism

Assessment methods include:

- Multiple-choice questions (MCQs) testing theoretical knowledge of innovation methodologies, business fundamentals, and risk management frameworks
- Short Answer Questions focused on the application of concepts to specific 5G market opportunities
- Problem-Solving Questions requiring analysis of telecommunications venture challenges
- Business plan development and presentation with structured evaluation rubrics assessing feasibility, market understanding, and financial projections
- Pitch deck creation and delivery with feedback on clarity, persuasiveness, and investor readiness
- Market analysis report evaluated on research quality, insight depth, and actionable recommendations
- Leadership simulation assessment with defined competency metrics for team coordination, decision-making, and conflict resolution

Assessment Rubrics:

Each assessment includes detailed evaluation criteria. Below are some examples:

Innovation Challenge Rubric:

- Problem Definition (20%): Clarity and significance of the identified problem
- User Understanding (20%): Depth of user research and empathy
- Solution Creativity (30%): Originality and feasibility of proposed solution
- 5G Relevance (20%): Effective utilization of 5G capabilities
- Presentation Quality (10%): Communication effectiveness

Business Model Canvas Rubric:

- Value Proposition (25%): Clarity and differentiation

- Market Segments (15%): Precision and sizing
- Revenue Model (20%): Feasibility and scalability
- Cost Structure (15%): Comprehensiveness and realism
- Key Resources & Activities (15%): Alignment with business model
- Overall Coherence (10%): Logical consistency across elements

Feedback Mechanism:

- Automated feedback for MCQs with explanations for correct/incorrect answers
- Instructor feedback for written assessments using standardized rubrics
- Peer reviews for group projects using structured evaluation forms
- Mentor feedback from industry experts was provided during designated mentorship sessions
- Self-assessment reflections guided by competency frameworks

Recommended readings

Module 1 readings:

- Idris Mootee. Design Thinking for Strategic Innovation: What They Can't Teach You at Business or Design School. Wiley. https://www.wiley.com/en-us/Design+Thinking+for+Strategic+Innovation:+What+They+Can%27t+Teach+You+at+Business+or+Design+School-p-9781118620120
- Eric Ries. The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses. Publisher listing/abstract. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1540-5885.2012.00920_2.x
- Selected case studies on 5G innovation and entrepreneurship. GSMA. The 5G Guide (open report with cases/use cases and investment context). https://www.gsma.com/wp-content/uploads/2019/04/The-5G-Guide_GSMA_2019_04_29_compressed.pdf

Module 2 readings:

- Leadership in the 5G Era (relevant textbook substitute with accessible report). GSMA. The 5G Guide (leadership/organizational readiness sections). https://www.gsma.com/wp-content/uploads/2019/04/The-5G-Guide_GSMA_2019_04_29_compressed.pdf
- Ken Watanabe. Problem Solving 101: A Simple Book for Smart People. Google Books bibliographic entry. https://books.google.com/books/about/Problem_Solving_101.html?id=NSZ-AQAACAAJ
- Case studies of successful 5G startup leaders. GSMA. The 5G Guide (ecosystem and use-case vignettes). https://www.gsma.com/wp-content/uploads/2019/04/The-5G-Guide_GSMA_2019_04_29_compressed.pdf

Module 3 readings:

- Karen Berman & Joe Knight. Financial Intelligence for Entrepreneurs: What You Really Need to Know About the Numbers. Google Books bibliographic entry.

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https://books.google.com/books/about/Financial_Intelligence_for_Entrepreneurs.html?id=DOPI3EaK80wC

- Philip Kotler, Hermawan Kartajaya, Iwan Setiawan. Marketing 5.0: Technology for Humanity. Wiley product page. https://www.wiley.com/en-br/Marketing+5+0:+Technology+for+Humanity-p-9781119668510
- Industry reports on 5G business strategy and investment. GSMA. The 5G Guide (deployment, economics, investment). https://www.gsma.com/wp-content/uploads/2019/04/The-5G-Guide_GSMA_2019_04_29_compressed.pdf

Module 4 readings:

- Nassim Nicholas Taleb. Antifragile: Things That Gain from Disorder. Publisher/bookseller landing (ISBN info). https://www.barnesandnoble.com/w/antifragile-nassim-nicholas-taleb/1110867836
- Keith Ferrazzi (with Tahl Raz). Never Eat Alone: And Other Secrets to Success, One Relationship at a Time. Bookseller landing (ISBN info). https://www.abebooks.com/9780385512053/Never-Eat-Alone-Secrets-Success-0385512058/plp
- White papers on risk management in telecommunications ventures. GSMA. The 5G Guide (risk/operational complexity, coexistence, organizational capabilities). https://www.gsma.com/wp-content/uploads/2019/04/The-5G-Guide_GSMA_2019_04_29_compressed.pdf

Development of Soft Skills

The course integrates soft skills development through:

- **Team-based projects** with defined roles and structured peer feedback
- Presentations with video recording and professional critique
- **Problem-solving tasks** requiring cross-functional collaboration
- **Leadership exercises and role-playing** with reflective analysis
- **Networking exercises and events** with industry professionals
- **Conflict resolution scenarios** based on real startup challenges
- **Emotional intelligence development** through failure simulation exercises

The soft skills are not evaluated separately but rather as part of collaborative activities, and through instructors' feedback, they will be enhancing the overall learning experience of students.

Industry Collaboration and Internships

Partnerships with telecom companies provide opportunities for:

- Guest lectures by industry experts
- Guest lectures by successful B5G entrepreneurs
- Mentorship from industry professionals
- Real-world case studies and challenges

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- Networking events with industry stakeholders

Accessibility and Inclusivity

The course ensures inclusivity through:

- Transcripts and subtitles for video content
- Language support for non-native speakers (e.g., screen-reader)
- Adaptations for learners with disabilities

ECVET/ECTS Credit Allocation

The total course is allocated 2 ECTS, distributed across modules as follows:

Module 1: 0.5 ECTS (15 hours)

Module 2: 0.5 ECTS (15 hours)

Module 3: 0.5 ECTS (15 hours)

Module 4: 0.5 ECTS (15 hours).

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ANNEX II. Learner Feedback Questionnaire Used in the Pilot Phase

This annex provides the learner feedback questionnaire used during the pilot phase of the 5G-DiGITs courses. The same evaluation structure was applied across the course portfolio in order to collect comparable feedback on course organisation, learning materials, pedagogical approach, digital delivery, and, where applicable, problem-based learning activities

Course title

Learner profile

Please indicate your learner profile:

- Bachelor
- Master
- PhD

Scoring system

For each statement, please select a score from **1 to 5** and, where appropriate, add optional comments.

- **1** = Very Poor
- **2** = Poor
- **3** = Average
- **4** = Good
- **5** = Excellent

---

1. Introduction

Please rate each statement from **1 to 5** and optionally provide comments.

1.1 Initial level of knowledge

What was your initial level of knowledge in this course?
Score: 1–5
Comments (optional):

1.2 Knowledge and skills improvement

Do you consider that the material offered has improved / can improve your knowledge and skills in this subject?
Score: 1–5
Comments (optional):

1.3 Relevance to current trends

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How relevant do you find the course content to the current trends in the field?
Score: 1–5
Comments (optional):

1.4 Fit to your profile

Do you consider that the course and materials are adapted to the needs of your academic or professional profile?
Score: 1–5
Comments (optional):

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2. Overall Impression

Please rate each statement from **1 to 5** and optionally provide comments.

2.1 Structure and organisation

The structure is coherent and easy to follow; modules and units are clearly organised.
Score: 1–5
Comments (optional):

2.2 Clarity and consistency

Terminology and methodology are consistent and understandable; relevant terms are explained clearly and used consistently.
Score: 1–5
Comments (optional):

2.3 Alignment

Modules, units, assessments, and learning outcomes align properly; learning activities support the intended learning goals.
Score: 1–5
Comments (optional):

2.4 Engagement and satisfaction

The course can keep student interest and meets your expectations.
Score: 1–5
Comments (optional):

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3. Learning Objectives, Materials, and Methods

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Please rate each statement from **1 to 5** and optionally provide comments.

3.1 Theory-practice connection and participation

The course clearly connects theory and practice and encourages student participation.
Score: 1–5
Comments (optional):

3.2 Clarity and consistency

Terminology and methodology are consistent and understandable; relevant terms are explained clearly and used consistently.
Score: 1–5
Comments (optional):

3.3 Quality and alignment of materials

Course materials and lectures align with the learning objectives and support your understanding.
Score: 1–5
Comments (optional):

3.4 Assessment usefulness

Assessments (quizzes, assignments, activities) are appropriate and helped / can help you verify or improve your learning.
Score: 1–5
Comments (optional):

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4. Pedagogical Approach

Please rate each statement from **1 to 5** and optionally provide comments.

4.1 Theoretical foundation

The course ensures a solid base of theoretical knowledge.
Score: 1–5
Comments (optional):

4.2 Practical application

Practical exercises/case studies enabled/can enable you to apply what you learned.
Score: 1–5
Comments (optional):

4.3 Digital tools integration

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LMS (Learning Management System) and digital/collaborative tools are used meaningfully to support the learning objectives.
Score: 1–5
Comments (optional):

4.4 Teaching methodology

Teaching methods are appropriate and, where relevant, innovative for the topic.
Score: 1–5
Comments (optional):

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5. PBL Assessment

(Only for courses/units using Problem-Based Learning)

Please rate each statement from **1 to 5** and optionally provide comments.

5.1 Usefulness of case studies/problems

How helpful are the case studies/problems in enhancing your learning experience and contributing to your understanding of the course content?
Score: 1–5
Comments (optional):

5.2 Authenticity and alignment

The problem scenario(s) are realistic/authentic, and they are clearly aligned with the intended learning objectives.
Score: 1–5
Comments (optional):

5.3 Self-directed learning

The PBL activity encourages active investigation (searching, selecting, and applying information/resources) to solve the problem.
Score: 1–5
Comments (optional):

5.4 Reflection and transfer

The PBL activity encouraged/can encourage me to reflect on my reasoning and to transfer what I learned to new or real-world situations.
Score: 1–5
Comments (optional):

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6. Additional Comments

Would you like to include any additional feedback (strengths, weaknesses, suggestions for improvement)?

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