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Deliverable D1.1:
Master's in Cyber Security: Curriculum Design

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Abstract

Report on the design phase of the curriculum of the master's programme in Cybersecurity. The report describes the labour market needs analysis carried out by the consortium and presents the final curriculum of the master's programme. The Curriculum of the Master's programme is designed on the analysis of the existing literature linked to the needs of the European labour market in digital skills and in the broad field of Cybersecurity. ELTE leads a consortium of 7 higher education Institutions from 6 different countries.

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Versioning and contribution history

Version	Date	Authors	Notes
0.1	07/06/2024	Viktoria Villanyi (ELTE)	First version.
0.2	07/06/2024	Antonio Faonio (EURECOM)	Provided information about EURECOM's curriculum
0.3	07/06/2024	Bruno Crispo (UNITN)	Provided information about UNITN's curriculum
0.4	07/06/2024	Darius-Vasile Bufnea(UBB)	Provided information about UBB's curriculum
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0.6	07/06/2024	Florian Hahn(UT)	Provided information about UT's curriculum
0.7	07/06/2024	Seppo Virtanen (UTU)	Provided information about UTU's curriculum
0.8	09/07/2024	Viktoria Villanyi (ELTE)	Revised details on master programmes.
0.9	19/07/2024	Viktoria Villanyi (ELTE)	Labour market analysis updated
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0.11	29/07/2024	Darius-Vasile Bufnea(UBB)	Labour market analysis updated (UBB)
0.12	29/07/20024	Florian Hahn(UT)	Labour market analysis updated (UT)
0.13	31/07/2024	Bruno Crispo (UNITN)	UNITN's curriculum updated
0.14	28/08/2024	Andrea Biancini (EITD)	Final version formatting.

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1 Labour market analysis

1.1 Introduction

Ensuring the security of IT infrastructure is becoming increasingly challenging. We are fully connected in the online space, and the shift to remote work during the pandemic has moved many of our activities online. Our everyday lives are heavily impacted by online services. While we consider security measures against various adversaries, we must also protect our systems from innocent human errors.

One notable example of IT outage occurred on July 19, 2024, when Crowdstrike, a well-established cybersecurity company with a 24% market share in endpoint-protection market, and close ties to Microsoft, released an update containing a bug. This mistake led to a global IT outage on an unprecedented scale, affecting airports, banks, hospitals, and causing widespread disruption and financial losses. Even this incident that involves major cybersecurity companies highlights the critical importance of the field of cybersecurity.

The first part of our labour market analysis of the field of Cybersecurity based on the European Cybersecurity Skills Framework [1], researched and documented by European Union Agency for Cybersecurity (ENISA). The main purpose of the European Cybersecurity Skills Framework research was to create a common understanding between individuals, employers and providers of learning programs across EU Member States. This makes it a valuable tool to bridge the gap between the cybersecurity professional workplace and learning environments.

1.2 Cybersecurity workforce

The cybersecurity workforce is reaching an all-time high with an estimated 5.5 million professionals already employed worldwide. However, there is still a global shortage of 3.9 million workers in this field [2]. ISC2 estimates an 8.7% increase year over year and nearly 440,000 new jobs, but the gap between the number of workers needed and the number available has continued to grow, with a 12.6% increase year over year. According to an assessment by the International Information System Security Certification Consortium [3], Europe faces a deficit of over 347,000 cybersecurity professionals.

1.3 Diversity

The cybersecurity workforce faces a significant diversity challenge. Women constitute only 24% of the global cyber security workforce [3]. Among OECD countries, some like Israel (53%), Norway (31%), Canada (28%), and Sweden (27%) have a higher percentage of women among ICT graduates, while others like France (17%)have a lower percentage, partly due to the small proportion of women trained in the information and communication technology field overall[2].

Our EITD's historical data on diversity is slightly better. The percentage of the female students in our EITD Cyber Security Programme (our predecessor Cyber Security Programme) was 26% in cohort 2023 and 33% in cohort 2022.

1.4 The typical cybersecurity professional role profiles

ENISA defined the following 12 typical cybersecurity professional role profiles [1]:

1. Chief Information Security Officer (CISO)
2. Cyber Incident Responder
3. Cyber Legal, Policy & Compliance Officer
4. Cyber Threat Intelligence Specialist
5. Cybersecurity Architect
6. Cybersecurity Auditor
7. Cybersecurity Educator
8. Cybersecurity Implementer
9. Cybersecurity Researcher
10. Cybersecurity Risk Manager
11. Digital Forensics Investigator
12. Penetration Tester

These profiles provide a common understanding of the main cybersecurity missions, tasks, and skills needed in a professional cybersecurity context, making it the perfect reference for profiling skills and knowledge needed by cybersecurity professionals. The needed skills and sets of knowledge for different profiles can be very distinct. The field of cybersecurity need professionals with diverse background and different skill sets, who should acquire the necessary knowledge along their study or training programmes.

1.5 General knowledge required by cybersecurity professionals

In the same study [1], ENISA collected a list of essential knowledge required to perform work functions and duties for the profiles. According to the study, most of the cybersecurity professional role profile need the following knowledge:

1. Cybersecurity-related certifications
2. Cybersecurity controls and solutions
3. Cybersecurity standards, methodologies, and frameworks
4. Computer network security
5. Cyber threats
6. Cybersecurity recommendations and best practices
7. Cybersecurity-related laws, regulations, and legislations
8. Operating systems security
9. Computer systems vulnerabilities
10. Cybersecurity attack procedures
11. Computer programming
12. Cybersecurity-related technologies
13. Legal, regulatory, and legislative compliance requirements, recommendations, and best practices

During the first year of the SPECTRO programme, our students obtain solid knowledge of all these covered by our common core courses, or they have already acquired this knowledge during their Computer Science BSc program (e.g., computer programming). In the second year, we focus on more specialized, advanced technical topics based on the current work environment requirements and the interest of our MSc students. We are keep updating and improving our programme based on the new results and challenges from IT word.

1.6 The required skill set for cybersecurity professional roles

The required skill set for the 12 typical cybersecurity professional role profiles was defined by ENISA [1]. Here is a collection of skills that are demanded by more than one profile, with the exact number of profiles needing each skill indicated in parentheses:

1. Communicate, present and report to relevant stakeholders (8)
2. Identify and solve cybersecurity-related issues (5)
3. Collaborate with other team members and colleagues (4)
4. Decompose and analyse systems to identify weaknesses and ineffective controls (3)
5. Collect, analyse and correlate cyber threat information originating from multiple sources (2)
6. Communicate, coordinate and cooperate with internal and external stakeholders (2)
7. Conduct technical analysis and reporting (2)
8. Decompose and analyse systems to develop security and privacy requirements and identify effective solutions (2)
9. Motivate and encourage people (2)

It is evident that soft skills related to the cybersecurity profession are increasingly important. Our education model emphasizes activities that support the development of soft skills next to the development of hard skills, such as the Kick-Off event, and I&E-related courses (30 ECTS). The SPECTRO education programme focuses on developing the necessary basic and the competitive advanced technical skills by offering a 90 ECTS technical part of the education programme. Our Cyber Security MSc programme offers 7 different advanced technical specializations. Online certification programmes for professionals will also be offered contribute to the participants' life learning journey of studying. Our programme is upskilling and reskilling the workforce in the EU.

1.7 Skill gaps (technical skills)

In the Cybersecurity Workforce Study [3], many organizations reported skills gaps. These are the most common (technical) skill gaps in the field of cybersecurity nowadays according to the study:

- 1. Cloud computing security,
- 2. AI/ML and
- 3. Zero Trust implementation.

Historically, cloud computing security was the most common area where the organization reported a skills gap.

In 2023, for the first time, AI/ML skills were among the top five in terms of demand. Last year, AI/ML skills were among the least significant, but they are becoming increasingly important and soon critical.

The organization also has a shortage of cybersecurity staff needed to prevent and troubleshoot security issues.

Other identified technical skills gaps include penetration testing, application security, digital forensics and incident response, risk assessment, analysis and management, security engineering, threat intelligence analysis, and malware research/analysis.

1.8 Local Labour Market Analysis

Our Cyber Security Consortium consists of seven partner institutes. Based on the results of literature review on Cyber Security and labour market analyses, the partners have developed an up-to-date Cyber Security Programme with new and revised exit year specializations. In the following subsections, the partners explain the reasons of these changes.

1.8.1 Eötvös Loránd University (ELTE), Quantum-resistant specialization

The European Commission encourages member states to develop a comprehensive strategy for the adoption of post-quantum cryptography to ensure a coordinated and synchronized transition among the different Member States and their public sectors [4].

US National Institute of Standards and Technology (NIST) has launched initiatives to standardize a new type of cryptography called quantum-resistant cryptography. NIST has selected four algorithm for standardization (2022) that can withstand attacks from both classical and quantum computers. It is critical to prepare now to migrate to the new standards as soon as possible protect privacy and provide security in the near future.

The new Quantum-resistant Cryptography specialization will prepare our students for the challenges of the time when quantum computers become a reality, and the widely used old public key algorithms will be insecure and breakable in polynomial time. We should start using quantum-resistant algorithms even before the appearance of quantum computers. We have already entered the period of "harvest now, decrypt later," also known as "store now, decrypt later," when we will be able to run quantum algorithms.

1.8.2 Babeș-Bolyai University (UBB), Software Security

The Faculty of Mathematics and Computer Science of the Babeș-Bolyai University (UBB) is in contact with several dozen companies, mostly from the IT&C field. These companies vary in type, ranging from small startups and SMEs to large multinational corporations. The collaboration with these companies takes various forms: they offer internship positions to Babeș-Bolyai students, provide private scholarships, and their representatives are invited to deliver guest lectures to students, among other activities.
The UBB Computer Science Department also maintains periodic contact with these companies, either through their representatives at invited lectures or through regular meetings at various events such as Internship Workshop Day, Graduation Day or the Student Scientific Communications Session (SCCSS).

In the context of this project, these companies were invited to respond to a questionnaire whose primary goal was to assess the need for cybersecurity education both in general society and specifically within these companies. Additionally, it aimed to determine the competencies required of graduates and to shape the curriculum for such programs based on specific industry and societal needs.

The Faculty of Mathematics and Computer Science received 26 responses to this questionnaire at the time of completing this report, including responses from strategic partners such as Computacenter, NTT Data, Bitdefender, and Siemens. It is noteworthy that Computacenter and NTT Data support various educational programs within the faculty, with Computacenter even providing a support fund for private scholarships for cybersecurity students. Additionally, Bitdefender, a

major player in the IT&C sector specializing in cybersecurity, has pledged to support UBB's cybersecurity master's program from the first SPECTRO cohort with an optional course on Extended Detection and Response.

From all the companies that responded to the questionnaire, 100% of the respondents consider that, given the current state of Internet development and the information society, as well as the current geopolitical context, cybersecurity and cybersecurity education are extremely important for any company, institution, organization, and for society in general. Approximately two-thirds of the respondents (65.4%) consider that cybersecurity education should take place at the master's level, while approximately one-third of the respondents (34.6%) believe that cybersecurity education should occur at the undergraduate level. A vast majority of respondents (96.2%) considered that software security should be the main focus of these studies, while only 3.8% of respondents felt that such studies should focus on hardware security. Additionally, considering the expertise of the faculty at Babeș-Bolyai University, a focus on software cybersecurity for such a master's program is a natural choice.

The companies surveyed were asked to identify essential knowledge, skills, and capabilities for graduates of cybersecurity educational programs. The key competencies highlighted include understanding main cyber threats, implementing security programs, and knowledge of common attack patterns and countermeasures. Graduates should have strong foundations in cybersecurity fundamentals, network security, cryptography, risk management, compliance, and emerging technologies. Essential skills include technical proficiency, analytical skills, programming, communication, and problem-solving. They should also be adept in information security principles, security policies, network architectures, secure software development, and regulatory issues. Practical abilities such as conducting risk assessments, incident response, penetration testing, and forensic analysis are critical. Additionally, graduates should be familiar with operating systems, network protocols, security tools, and frameworks. Understanding the legal, regulatory, and compliance landscape, such as GDPR is also crucial. The emphasis on software cybersecurity education reflects the industry's need for well-rounded professionals capable of addressing various cyber threats and implementing comprehensive security measures.

Most respondents confirmed that they had faced cybersecurity incidents or problems, with a vast majority of them (88%) willing to hire cybersecurity specialists in the future. They deal with social engineering attacks (e.g., phishing), technology-based threats (e.g., DoS attacks), and user errors. The shortage of cybersecurity specialists exacerbates these issues. Companies are tasked with implementing security measures with minimal impact on productivity, addressing threats such as phishing, LoTL attacks, and cryptojacking, and conducting vulnerability assessments. Securing

internal networks through independent penetration testing and managing application access are also critical. Other concerns include navigating complex security standards, cloud and IoT security, and compliance with frameworks like NIST2. Companies often encounter vulnerabilities in third-party libraries and must update these to prevent exploitation. They also face challenges in system integrations, protecting core data, and ensuring safe technology use while meeting customer expectations. Ultimately, securing enough cybersecurity professionals is essential to effectively address these needs.

Among the advantages of hiring cybersecurity specialists in the future, the companies that responded to the questionnaire highlighted that cybersecurity is increasingly critical due to the interconnected nature of software systems, with failures potentially halting their operations. Cybersecurity is becoming one of the most crucial aspects in technology and business continuity. Experienced specialists are needed to bring expertise in the complex field of cybersecurity, enabling them to implement robust measures that protect companies' infrastructure and applications. This approach helps in identifying and mitigating threats, ensuring compliance with industry standards and regulatory requirements such as GDPR for example. Additionally, cybersecurity specialists can tailor security solutions to an organization's specific needs, enhance data handling practices, and raise security awareness internally. Ultimately, expanding the team with skilled cybersecurity graduates not only safeguards operations but also creates opportunities for increased revenue by offering advanced cybersecurity solutions to other businesses.

1.8.3 University of Twente (UT), Circular Security

The Twente University Centre for Cybersecurity Research (TUCCR) is a public-private partnership between the University of Twente and its partners from industry with the goal to create innovation in form of technology, tools and knowledge making an impact on today's digital society. One key aspect towards a positive change is the education of the next generation of cybersecurity professionals. As reflected by the diversity of our industry partners[1] ranging from the banking sector and governmental institutions over classical ICT companies towards cybersecurity experts, the knowledge required from our graduates at University of Twente is just as diverse. Inspired by the research areas identified for TUCCR with our industry partners, we leverage SPECTRO to take the next step and align also our educational programme with these areas.

The specialisation in Circular Security covers the complete range of steps necessary to develop secure solutions for the real world: starting from the analysis of known cyber-harm, -attacks and -vulnerabilities and their proper modelling, to the engineering of targeted protection, mitigation,

[1] https://www.utwente.nl/en/digital-society/research/Cybersecurity_tuccr/people/partners/

detection, and response solutions, all the way to their implementation and extensive testing. For each of these steps, we acknowledge the importance of the socio-economic context and the involved human factor, which can be part of the problem and part of the solution at the same time.

1.8.4 University of Turku (UTU), Security Technologies and Intelligence specialization

Based on the market research and analysis, the specialisation offered by the University of Turku (UTU) was revised to "Security Technologies and Intelligence".

A stakeholder study was made in Finland during spring 2024 jointly by the leading Finnish universities offering cyber security education. The study was led by UTU. The stakeholders (companies and organizations in the cyber security field or in need of cyber security professionals) were asked to rate their skill needs in the JRC Cybersecurity Taxonomy [5] topics currently and in the near future. In addition to JRC taxonomy items, also the skill need for artificial intelligence and machine learning in the cyber security context was added as a topic in the survey due to their current disruptive effect across the ICT field.
Altogether 61 companies and organizations answered the survey and further details were received through interviews of respondents that indicated there willingness in the survey to participate in interviews.
Altogether 12 interviews were made among the different companies and stakeholders. The 61 respondents consisted of both national and international companies and organizations but with the respondents representing the stakeholders' Finnish branches in the case of international companies and organizations.

The analysis of the survey results revealed that artificial intelligence and machine learning in the cyber security context, data security and privacy and software and hardware security engineering were among the top three skill needs for the future among the respondents. The analysis made based on these results and all the more detailed results obtained in the Finnish market survey were used as a key input in the spring 2024 cyber security curriculum design for SPECTRO at UTU, resulting in a revised focus in the specialisation.

The revised (new) Security Technologies and Intelligence specialisation at UTU focuses on researching pre-emptive, reactive and analytical security technologies to protect systems from cyber threats and malicious exploitation attempts in the era of artificial intelligence and machine learning. The compulsory studies are on intelligent technologies for protecting systems and networks (firewalls and intrusion prevention), ethical hacking (penetration testing) and analysing digital traces of malicious activity (digital forensics). The revised specialisation reflects very well the analysis results of the market research performed in Finland in spring 2024.

The revised specialisation gives its students profound and substantial education and expertise in the field. Optional studies selected personally for each student build a special individual cyber security expertise profile. The curriculum consists of both theoretical and hands-on study modules. Also, a large group project module called 'Capstone project' can be included in the studies. The graduates of the revised specialisation will have a strong technological, theoretical and practical understanding of security technologies for protecting systems and environments against cyber threats. With these new skills and knowledge, graduates can proceed to building a successful career in securing and protecting the ICT intensive industry. The graduate's unique expertise profile may lead to a career title of, for example, one of the following: Cyber Security Analyst, Penetration and Vulnerability Tester, Cyber Security Consultant, Cyber Security Manager, Network Security Specialist, Cyber Security Entrepreneur, System / Network Administrator, Business Information Security Officer, Chief Information Officer, Chief Information Security Officer, Head of Corporate IT.

1.9 Literature used for the labour market analysis

1. European Cybersecurity Skills Framework (ECSF): https://www.enisa.europa.eu/topics/education/european-cybersecurity-skills-framework
2. OECD (2024), Building a Skilled Cyber Security Workforce in Europe: Insights from France, Germany and Poland, OECD Skills Studies, OECD Publishing, Paris, https://doi.org/10.1787/3673cd60-en.
3. ISC2, 2023 Cybersecurity Workforce Study (2023), https://www.isc2.org/Research
4. Recommendation on a Coordinated Implementation Roadmap for the transition to Post-Quantum Cryptography: https://digital-strategy.ec.europa.eu/en/library/recommendation-coordinated-implementation-roadmap-transition-post-quantum-cryptography
5. Nai Fovino, I., Neisse, R., Hernandez Ramos, J., Polemi, N., Ruzzante, G., Figwer, M., & Lazari, A. A Proposal for a European Cybersecurity Taxonomy. In EUR 29868 EN. Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-11603-5, doi:10.2760/106002, JRC118089.
https://op.europa.eu/en/publication-detail/-/publication/a1fcc114-01eb-11ea-8c1f-01aa75ed71a1/language-en

2 Programme objectives

The Cyber Security program (previously known as Security and Privacy) is a Masters level program within the EIT Digital Master School. The Master School is a highly prestigious ICT engineering education provider on advanced level with a business minor focused on Innovation and Entrepreneurship (I&E). These students will be an elite group of forthcoming ICT professionals. The unique features of this advanced level education are:

- A standardized I&E minor.
- Personal industrial relationships for the students, including industrial mentors and internships.
- Thematic area grounding and utilization of resources from EIT Digital innovation activities.
- Utilization of EIT Digital co-location center (CLC) resources.
- Inter disciplinary and inter node teambuilding events**.**

3 Structure

The Cyber Security program is a comprehensive combination of an I&E Minor (30 ECTS) and a Technical (major) (90 ECTS):

- 20-30 ECTS mandatory courses ('common base')
- 30-40 ECTS elective and specialized courses ('specialisation')
- 30 ECTS master's thesis project.

Typically, during the entry year, students have to take 36 ECTS for the technical major and 24 ECTS for the minor in Innovation & Entrepreneurship whereas during the second year, they have to take 24 ECTS for the technical major, 6 ECTS for the minor and 30 ECTS for the master thesis project.

All Master School education will be held in English and all partner universities are assumed to use ECTS units.

The learning objectives of the Cyber Security Master are that a graduate:

- Understanding the concepts and technologies for achieving confidentiality, integrity, authenticity, and privacy protection for information processed across networks.

- Mastering the key principles underlying a constructive approach to secure systems, including threat characterization and subversion; confinement; fundamental abstractions, principles, and mechanisms; and life-cycle assurance.

- Being able to apply fundamental Information Systems Security Engineering principles and processes, as applied to the stages a life-cycle model in the context of a defence-in-depth protection strategy

- Recognizing potential vulnerabilities in networked systems by studying methods to obtain information about remote networks and how to exploit or subvert systems on that network.

- Being able to use current tools and techniques for assessing network attacks and vulnerability and for systematically reducing vulnerabilities and mitigating risks.

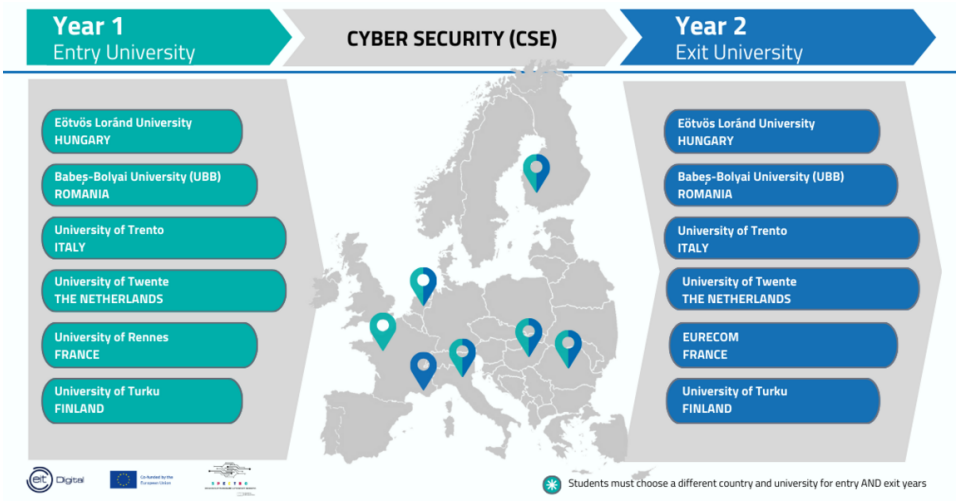
- Ability to examine security engineering concepts and practices from a system lifecycle perspective based on a "systems thinking" approach that supports assessment of system security behaviours based on dependencies, interactions, and emergent properties of system components in the context of functionality, scalability, interoperability, and maintainability.

- Competences in communication, knowledge integration, open innovation and technology management from the viewpoints of both business and technology.

- Business skills to understand and execute a business development process, and have insight in legal and societal aspects of security and privacy.

Those outcomes of the Cyber Security major will be combined with the I&E minor to enable graduated students to create or get involved in start-up companies, and lead innovation in existing companies developing the data value chain and monetize data. In summary, create a new corpse of professionals for a career in a highly innovative area of Cyber Security.

4 Partners in the Consortium



- Eötvös Loránd University, ELTE, Hungary
- Babeș-Bolyai University, UBB, Romania
- University of Trento, UNITN, Italy
- Universiteit Twente, UT, The Netherlands
- University of Turku, UTU, Finland
- University Rennes, UR, France
- EURECOM, EUR, France

All involved University Parties are recognized degree awarding institutions. An EIT Digital technical major + I&E minor leads, upon successful completion, to two officially recognized Master of Science Degrees (120 ECTS) issued by the entry university and the exit university. A double degree will be awarded. The students are also awarded an EIT Label Certificate issued by EIT Digital. The Certificate is based on the two degrees issued by the partner institutions and summarizes the EIT label and EIT Digital Master School specific characteristics of the education.

Program details (modules, courses) and individual grades/marks are described in the Degree Certificates/Official transcripts. Exceptions to this rule of awarding double degrees are not possible

unless specifically confirmed by written agreement between the Parties and must be communicated to the affected students in a timely manner.

5 Responsabilities of the partners

The following universities provide a first year:

- Eötvös Loránd University, ELTE, Hungary
- University Rennes, UR, France
- Babeș-Bolyai University, UBB, Romania
- University of Trento, UNITN, Italy
- Universiteit Twente, UT, The Netherlands
- University of Turku, UTU, Finland

The following parties provide an exit year and every exit University is supposed to define its own unique specialisation:

- Eötvös Loránd University, ELTE, Hungary
- EURECOM, EUR, France
- Babeș-Bolyai University, UBB, Romania
- University of Trento, UNITN, Italy
- Universiteit Twente, UT, The Netherlands
- University of Turku, UTU, Finland

6 Learning Objectives

The courses offered in the Cyber Security programme give a common background at the Entry institutions, while the Exit points are specialised on specific topics.

Computer Security:

Definitions of basic security terms, Security Goals (CIA), Risks, Vulnerabilities, Attacks, Basic Cryptography and Cryptography Protocols (e.g., Kerberos, SSL), Threats in IT systems (Malware, targeted attacks, …), Security Mechanisms (Authentication, Access Control, Network Security FW IDS, Browser, Email), Physical Security Example Literature: Ross Anderson: Introduction to Computer Security, William Stallings: Computer Security – Principles and Practice.

Network Security:
Firewalls, IDS (signature-, anomaly-based), IPsec (IKE), Malware, Remote Attacks, Protocol Attacks (ARP, DNS, Routing, ICMP), Non-IP Network Security (SS7, layer 2), Mobile Networks (WLAN). Example Literature: William Stallings: Network Security – Principles and Practice.

System security:
Overflows Attacks, Language-level security, Application-level security, Webbased Attacks (OWASP), Formal verification, Sandboxing, Isolation. Example Literature: Gary McGraw: Software Security Library.

Information Security Management:
Security policies. Roles. Classifications. Assets and threats. Risk, vulnerability, control, attack, damage. Risk analysis. Methods/tools for risk analysis. CERTs. Risk assessment and risk management. Code of Practise for Information Security (BS7799). Evaluation of information security, like ITSEC and the Common Criteria. Security plan, attack trees, business continuity planning/incident recovery. Legal issues: patents and copyright.

Cryptography:
Advanced Cryptography, Cryptoanalysis, Randomness, Adversary Models, Zero- Knowledge, SideChannel Attacks. Example Literature: Henk van Tilborg: Fundamentals of Cryptology, Stallings: Cryptography & Network Security – Principle and Practice.

Privacy:
Privacy, Data Protection, Legal Basis, Privacy Enhancing Technologies, Privacy by Design, Privacy Assessment, Location Privacy.

The above common technical content is delivered through different sets of mandatory and elective courses at the entry universities.

6.1 Specialisation courses (second year)

Technical specialisations offered by the Exit Universities in the second year of the programme, alongside with theI&E courses, are:

ELTE: Advanced Cryptography

The specialisation focuses on the general ideas, techniques and methods of applied cryptography as well as on the theoretical background and solid knowledge, putting security in a wider context. Security and privacy are considered both from the technological and from the economical point of view, which supports decisions in many practical cases. Applied cryptography serves as a base for most of the secure IT-systems (e.g. in Future Media and Content Delivery, Smart Spaces, Digital cities, Health and ICT-Mediated Human Activity, and Enabling the Internet of the Future).

ELTE: Quantum-resistant Cryptography

The specialisation focuses on the general ideas, techniques and methods of security in the coming era of quantum technology. The theoretical background gives a solid understanding of cryptographic aspects and supports technological and economical decisions on security. In order to maintain security and privacy of IT systems (e.g. in Future Media and Content Delivery, Smart Spaces, Digital cities, Health and ICT-Mediated Human Activity, and Enabling the Internet of the Future) when quantum devices are around, new physical communication layers, novel computational architecture and cryptographic protocols may be used. Quantum-resistant cryptography serves as a base to understanding and overcoming these challenges.

EURECOM: Big Data Security

EURECOM is offering a specialisation in Big Data Security that aims at providing a solid knowledge of security in cloud computing and networking combined with practical design and management skills. The students learn how to identify threats, vulnerabilities and privacy problems in networks and cloud systems including the Internet of Things. They learn to integrate security solutions to a cloud computing platform and explore methods for holding cloud stakeholders accountable for the privacy and confidentiality of data in cloud systems.

The curriculum has a hands-on approach that combines laboratory work with classroom education, makes use of high-profile industry speakers to introduce the latest technologies, and includes a supervised semester-long team project on a topic of industrial relevance. One focus area is communication and organizational skills together with project planning and implementation competencies. A mandatory management course fosters an entrepreneurial mindset, and the elective courses enable students to further explore data science or networking.

UBB: Software Security

This master's programme offers a multiple perspective on the field of cyber security, addressing issues related to its various components: operating system security, network security, organisation and business process security, with a strong emphasis in the second year on the security of the software itself.

The courses in the 2nd year will have a strong focus on knowledge about 'Software Security', which is also the specialisation of the exit year. Students will be able to take courses like: Advanced Software Security, Securing Mobile Applications, Program Analysis for Software Security, and Cloud Application and Infrastructure Security. These courses will address advanced topics such as: software quality models, security as a quality factor in software, security analysis and verification of software, design of security checking tools, cloud and mobile application security. The overall goal of this specialisation is for students to understand the secure by design principles and assess different software security issues, in order to learn how to detect security vulnerabilities as soon as possible in the development cycle and to develop a more secure software from design to implementation. Also, a new course on XDR (Extended Detection and Response) is offered in cooperation with an industry partner, students having the opportunity to learn how to technically address security incidents.

The programme also has a strong emphasis on practical knowledge in the field of cyber security, the curricula being discussed with a number of companies that offer services and solutions in this field. Some of the students' activities, such as the internship or the thematic projects, can be carried out in partnership with the partner companies/industry in the field. The latter have a strong local presence, the city of Cluj-Napoca, Romania, being known as a strong development hub in the field of IT&C.

UNITN: System Security

In recent years, the most popular computing and communications platforms have changed dramatically from old desktops and personal computers to a myriad of new devices, often embedded and personal usually interconnected using several communications technologies. Such novel platforms have pervaded all economic sectors, also those traditionally relying on analog technology. This revolution has touched private, business and governmental domains (e.g., industry 4.0, smart-homes, critical infrastructures, automotive, smart cities, etc.). This in turn has created entire new ecosystems that include technical, social and economic factors.

The specialisation System Security focuses on addressing security and privacy for these new ecosystems trying a holistic approach that does not focus only on technical issues. Of course, it covers the technological aspects such as investigating and experimenting new class of threats and vulnerabilities, developing new technology to establish trust, designing novel way to authenticate users and machines. But it covers also, methodology to assess and enhance the security of the software development process and the economic aspects that are crucial to understand attackers, their motivations and to design effective defence strategies

UT: Circular Security

With the transformation into a digital society, our world is relying more and more on interconnected ICT systems. Despite this increasing dependency on computer systems, cybersecurity is still often an afterthought and only considered at the end of the development process or even later during deployment; think about IoT devices that are installed in isolated networks or zero-day exploits that are patched in live systems.

It is common practice to offer only time-limited support after release and end-of-life products do not receive further (security) updates. This planned obsolescence does not only lead to wasteful consumption of resources but also exposes computer networks with outdated systems to significant security risks.

Contradicting this practice, the adoption of computer systems into long-living facilities such as power-plants or cars leads to the new challenge of secure systems that stand the test of time. Notably, many risks for such systems are not solely of technical nature. Thus, we address the challenge of circular security from the technical perspective and complement it with socio-economic context.

Our specialisation looks at the many risks in the above-mentioned setting and provides mitigations that can be used already at the beginning of the design-phase. Additionally students get introduced to approaches for subsequent monitoring of live systems, while taking into account the specific requirements and the impact of various risks over the system's complete lifecycle.

UTU: Security Technologies and Intelligence

The Security Technologies and Intelligence specialisation focuses on researching pre-emptive, reactive and analytical security technologies to protect systems from cyber threats and malicious exploitation attempts in the era of artificial intelligence and machine learning. The compulsory studies are on intelligent technologies for protecting systems and networks (firewalls and intrusion prevention), ethical hacking (penetration testing) and analyzing digital traces of malicious activity (digital forensics).
The specialisation gives its students profound and substantial education and expertise in the field. Optional studies selected personally for each student build a special individual information security expertise profile. The curriculum consists of both theoretical and hands-on study modules. Also a large group project module called 'Capstone project' can be included in the studies.
The graduates of this specialisation will have strong technological, theoretical and practical understanding in security technologies for protecting systems and environments against cyber threats. With these new skills and knowledge, graduates can proceed to building a successful career in securing and protecting the ICT intensive industry. The graduate's unique expertise profile may lead to a career title of, for example, one of the following: Cyber Security Analyst, Penetration and Vulnerability Tester, Cyber Security Consultant, Cyber Security Manager, Network Security Specialist, Cyber Security Entrepreneur, System / Network Administrator, Business Information Security Officer, Chief Information Officer, Chief Information Security Officer, Head of Corporate IT.

7 Specific admission requirements

In order to be admitted students have to meet the admission requirements (e.g. grade point average, graduation session) of each partner University they apply to. The ineligibility of the students with respect to the admission requirements of one of the chosen Universities may limit their mobility options. These additional admission criteria must be specified clearly on the webpage of the concerned EIT Digital Master programme.

The specific admission requirements for the Cyber Security education are: A B.Sc. degree in electrical engineering/ electronics, computer engineering, computer science or information technology or applied mathematics is required. The studies should include at least 60 ECTS courses in computer science, computer architecture, or programming, and mathematics including calculus, algebra and mathematical statistics.

8 Degrees

The general degrees and legal frameworks for the EIT Digital partner universities are as follows:

- **Finland** UTU: Diplomi-insinööri, Diplomingenjör, Master of Science (Technology), Decree of the Council of State on University Degrees (1136/2009)
- **France** EUR and UR: DIPLÔME NATIONAL DE MASTER EN SCIENCES, TECHNOLOGIES, SANTÉ, MENTION INFORMATIQUE, PARCOURS SÉCURITÉ NUMÉRIQUE (Master of Science in Digital Security)
- **Italy** UNITN: Laurea Magistrale in Informatica - classe LM-18 (Master of Science in Computer Science) D.M. 270 dated 22 October 2004
- **The Netherlands** The Netherlands UT: Master of Science in Computer Science, Croho, 60300, 31-07-2014
- **Hungary** ELTE:"Master Degree" or "Magister" (abbreviated as MSc) (Section 52. Act. 5) and legal framework Act CCIV of 2011 On National Higher Education, National Assembly
- **Romania** UBB: SECURITATE CIBERNETICĂ. MASTER (CYBER SECURITY. MASTER'S DEGREE), HG 356/2023

9 Local programmes

The specific local master programs used for local implementation of this Cyber Security education are given below:

- **UTU:** Master's Degree Programme in Information and Communication Technology

- **UBB:** Cyber Security Master's Degree
- **EUR and UR:** M.Sc. in Digital Security
- **UT:** M.Sc. Computer Science
- **UNITN:** M.Sc. in Computer Science
- **ELTE**: M.Sc. in Computer Science

10 Grading systems

The involved Partner Universities use national grading systems. The table in Annex C, Section 9 will be used to relate credits in the different systems.

11 Guidelines

11.1 Guidelines for handling delays

The local guidelines of the partner which is responsible when a delay occurs and the general guidelines of the Master School Office shall be used to handle delays. In case of conflict, the corresponding guideline of the Master School Office shall be applied.

11.2 Guidelines for issuing Double Degrees

The local guidelines of both the Entry and the Exit University or Institution together with the general guidelines of the Master School Office are taken into account when issuing the Double Degree. Any potentially conflicting guidelines shall not be applied to the disadvantage of the degree candidate. In case of conflict the guidelines of the Master School Office concerning the specific matter shall be applied.

12 Conclusions

The field of cybersecurity is rapidly developing, with increasing challenges given by our growing dependence on the digital infrastructure. Despite significant growth in the cybersecurity workforce, the skills gaps persist and grow in many areas. This field still faces diversity challenges, women are underrepresented globally. Targeted education, upskilling, and continuous adaptation of cybersecurity programs are essential. Our approach is to align the curriculum with current and predicted market needs.

This deliverable provides a labor market analysis for cybersecurity and presents an updated curriculum for our Cyber Security MSc Programme based on the analysis.

13 Annex 1 –List of the courses for each Entry and Exit program

13.1 ELTE

13.1.1 Entry year

13.1.1.1 *First semester*

Compulsory Courses	(18 ECTS)
▪ Research Methodology	5
▪ Symmetric Key Cryptography	4
▪ Introduction to Offensive Security I.	4
▪ Privacy-enhancing Technologies	4
▪ Introductory Mathematics for Cybersecurity Specialisation	1
I&E	(10 ECTS)
▪ I&E Basic	6
▪ Business Development Lab I.	4

ha formattato: Italiano

13.1.1.2 *Second semester*

Compulsory Courses	(18 ECTS)
▪ Design and Analysis of Algorithms	4
▪ Public Key Cryptography	4
▪ Introduction to Data Security	4
▪ Advanced Software Technology	4
▪ Network Security	2
I&E	(14 ECTS)
▪ Innosocial Aspects of the Entrepreneurship	6
▪ Thematic Innovation & Entrepreneurship project	4
▪ Business Development Lab II	4

13.1.2 Exit year

13.1.2.1 *First semester*

Advanced Cryptography

Compulsory Course	*(24 ECTS)*
• Secure Multiparty Computation	4
• Zero-knowledge proofs and application	4
• Penetration testing	6
• Cryptographic Protocols	6
• Provably Secure Modular Design of Cryptographic Protocols	4
I&E (6 ECTS)	
• I&E Study	6

Quantum-resistant Cryptography

Compulsory Courses	*(24 ECTS)*
• Introduction to Quantum Information	4
• Post-quantum Cryptography	4
• Penetration testing	6
• Cryptographic Protocols	6
• Provably Secure Modular Design of Cryptographic Protocols	4
I&E	*(6 ECTS)*
• I&E Study	6

13.1.2.2 *Second semester*

- Master thesis (30 ECTS)

13.2 EURECOM

13.2.1 Exit year

13.2.1.1 *First semester*

Big Data Security

First Semester (30 ECTS)	*ECTS*
• UE Fundamentals EIT Digital Security (5 ECTS)	
• Security and Privacy for Big Data and Cloud	2.5
• Multipary Computation and Blockchains	2.5
• Mobile Systems and Smartphone Security	5
UE Electives EIT Digital Security (10 ECTS)	
• Machine Learning and Intelligent Systems	5
• Distributed Systems and Cloud Computing	5
• Quantum Information Science	5
• Digital Image Processing	5
• System and Network Security	5
• Mobile Communication Systems	5
UE I&E (6 ECTS)	
• Fundamental in Innovation and Entrepreneurship	6

- Semester Project (8 ECTS) 8
- UE Languages (1 ECTS)

13.2.1.2 *Second semester*

- Master thesis (30 ECTS)

13.3 UBB

13.3.1 Entry year

13.3.1.1 *First semester*

Compulsory Courses (17 ECTS) *ECTS*

- Cryptography 7
- Quality Aspects of Security in Software Testing 6
- Computer Ethics and Academic Integrity 4

I&E Compulsory Course (8 ECTS)

- Digital Economy Principles - I&E basics 8

I&E Elective Courses (5 ECTS)

- Agile Project Management 5
- Strategic Business Process Automation 5
- Business Forecasting and Predictive Modelling 5

13.3.1.2 *Second semester*

Compulsory Courses (12 ECTS) *ECTS*

- Web and Internet Security 6
- Security Audit and Risk Management 6

I&E Compulsory Courses (11 ECTS)

- Innovation Management - I&E Business Dev Lab 7
- Thematic Project with Innovation Challenge-EIT Digital Summer School 4

Elective Courses (7 ECTS)

- *Network Security and Administration* *7*
- Blockchain Security 7
- Complex Networks in Security 7
- Quantum Cryptography 7

13.3.2 Exit year

13.3.2.1 *First semester*

Software Security

Compulsory Courses(24 ECTS) *ECTS*

- Advanced Software Security 6
- Securing Mobile and IoT Software 6

- Program Analysis for Software Security 6
- Cloud Application and Infrastructure Security 6

I&E Compulsory Course *(6 ECTS)*

- Entrepreneurship in IT - I&E Study 6

Optional Course *(5 ECTS)*

- Extended Detection and Response 5

13.3.2.2 *Second semester*

Compulsory Course (30 ECTS) *ECTS*

- Internship in Specialisation 20
- Project in Cybersecurity 6
- Elaboration of the Dissertation Thesis 4

13.4 UR

13.4.1 Entry year

13.4.1.1 *First semester*

Compulsory Courses (20 ECTS) *ECTS*

- Basic Cryptography 5
- Low-Level Programming 5
- System Security 5
- Network Security 5

I&E *Courses (10 ECTS)* *ECTS*

- Innovation and entrepreneurship 5
- Business Development Laboratory 1 5

13.4.1.2 *Second semester*

Compulsory Courses (20 ECTS) *ECTS*

- Research Project 5
- Privacy 5
- System Security 5
- Software Exploitation 5

I&E *Courses (10 ECTS)* *ECTS*

- Business Development Laboratory 1 5
- Knowledge and Intangible Assets Management 5

13.5 EURECOM

13.5.1 EXIT year

13.5.1.1 *First semester*

Big Data

UE Data Processing and Architecture *(5 ECTS)*

- Computer Architecture
- Mobility Modelling
- Semantic Web and Information Extraction

UE Software & Systems *(10 ECTS)*

- Machine Learning and Intelligent System
- Mobile Communications Systems
- Mobile Applications and Services
- Software Development Methodologies
- Quantum Information Science
- Standardization Activities
- Designing Embedded Systems with UML

UE I&E *(6 ECTS)*

- Fundamental in Innovation and Entrepreneurship

Semester Project *(8 ECTS)*

UE Languages *(1 ECTS)*

13.5.1.1 *Second semester*

- Master thesis (30 ECTS)

13.6 UNITN

13.6.1 Entry year

13.6.1.1 *First semester and second semester*

Compulsory Courses (4 out of 5 for the total number of 24 ECTS)	*ECTS*
• Applied Cryptography	6
• Security Testing	6
• Cyber Security Risk Assessment	6
• Network Security	6
• Privacy and Intellectual Property Rights	6

Compulsory I&E Courses (24 ECTS)

• Innovation and Entrepreneurship Basics	6
• Business Development Laboratory	9
• ICT Innovation	

Elective Courses (12 ECTS)

13.6.2 EXIT year

13.6.2.1 *First semester and Second*

System Security

Specialisation Elective Courses (24 ETCS)	*ECTS*
• *Multimedia Data Security*	*6*
• *Ethical Hacking*	*6*
• *Study Project*	*6*
• *Blockhain*	*6*
• *Research Project*	*12*
• *Formal Techniques for Cryptographic Protocol Analysis*	*6*
• *Network Intrusion and Anomaly Detection with Machine Learning*	*6*
• *Embedded Systems*	*6*
• *Ethics for computer science and engineering*	*6*
• *Security experiments: attacks and defenses*	*12*

Compulsory I&E *Courses (6 ECTS)*

• Innovation and Entrepreneurship Studies in ICT	6

Internship	6
Master Thesis	24

13.7 UT

13.7.1 Entry year

13.7.1.1 *First semester*

Compulsory Major Courses (15 ECTS)	*ECTS*
• Cyber Risk Management	5
• Security and Cryptography	5
• Software Security	5
Compulsory I&E Courses (15 ECTS)	
• I&E Basics: Innovation Management for EIT	5
• Business Development Lab I	5
• Computer Ethics	5
Optional Courses	
• System Validation (only in comb. w/ SeV)	5
• Basic Machine Learning	5
• I&E: Brand Management	5
• Introduction to Biometrics	5
• Cyber Security Management	5
• Privacy-Enhancing Technologies Bootcamp	5
• Automated Vulnerability Research and Mitigation	5
• Distributed Systems	5
• [I&E] Empirical Methods for Designers	5
• I&E: Smart Industry	5

13.7.1.2 *Second semester*

Compulsory Major Courses (15 ECTS)	*ECTS*
• Internet Security	5
• System Security	5
Compulsory I&E Courses (5 ECTS)	
• Business Development Lab II	5
Optional Courses	
• Software Testing and Reverse Engineering	5
• Blockchain & Distributed Ledger Tech	5
• Cyber Data Analytics	5
• E-Law	5
• Security Services for the Internet of Things	5
• I&E for Venture Creation	4

13.7.2 Exit year

13.7.2.1 *First semester*

Circular Security

Compulsory I&E Courses (15 ECTS)	*ECTS*
• Computer Ethics	5
• I&E Study Tour	6
• Research Topics EIT	4

Specialisation Courses	*ECTS*
• Secure Data Management	5
• Secure Cloud Computing	5
• Cloud Networking	5
• Advanced Networking	5
• Empirical Security Analysis & Engineering	5
• Introduction to Biometrics	5
• Cyber Risk Management	5
• System Validation	5
• Design of Software Architectures	5
• Machine Learning 1	5
• Security Verification	5
• Distributed Systems	5
• Internet of Things	5
• Quantum Information	5
• Computer Ethics	5

13.7.2.2 *Second semester*

- Master thesis (30 ECTS)

13.8 UTU

13.8.1 Entry year

13.8.1.1 *First semester and second semester*

Compulsory Courses (31 ECTS)	*ECTS*
• System and Application Security	5
• Network Infrastructure Technologies and Security	5
• Human Element in Information Security	5
• Management of Information System Security	6
• Foundations of Cryptography	5

- Cryptography I 5

Innovation and Entrepreneurship

- Introduction to Innovation and Business 5
- Lean Digital Business Design 10
- I & E Project 4

Elective Courses (choose one)

- Knowledge and Innovation Management 5
- Enterprise Architecture 6
- Digital Business 3

13.8.2 Exit year

13.8.2.1 *First semester and second semester*

Compulsory Courses (15 ECTS) *ECTS*

- Firewall and IPS Technology 5
- Ethical Hacking 5
- Digital Forensics 5
- Master's Thesis in Technology 30

I&E (6 ECTS)

- I&E Study 6

Elective Courses

- *Communication Technologies and Security in IoT* *5*
- *Capstone Project* *10*
- *Cryptography 2* *5*
- *Algebraic Structures in Cryptography* *5*
- *Privacy and Security for Software Systems* *5*
- *Protocol Processing and Security* *5*
- *Security Engineering* *5*
- *Seminar 1 (TurkuSec meetings)* *1-5*
- *In addition to the courses listed above, a variety of courses qualifying as elective studies are available annually. Electives are chosen individually for each student when their personal study plan is made.*

References

[SPECTRO] http://eitdigital.eu/spectro/

Glossary

Community	A group of users, organised with a common purpose, and jointly granted access to resources. It may act as the interface between individual users and the resources. (see also [WISE-SCI])
EIT	European Institute of Innovation and Technology
KIC	Knowledge and Innovation Community
GDPR	General Data Protection Regulation
R&S	Research and scholarship