Applying LEAN-Principles on Cybersecurity Online Course: A Three-Year Longitude Study

Pasi Kämppi, Paresh Rathod and Jyri Rajamäki
Laurea University of Applied Sciences, Espoo, Finland

pasi.kamppi@laurea.fi
paresh.rathod@laurea.fi
jyri.rajamaki@laurea.fi

Abstract: Universities are increasingly pressured to work more efficiently with fewer resources while maintaining their relevance to the workforce and high educational quality. These demands are even higher in cybersecurity because the work-life indicates a competent workforce gap, and the availability of qualified instructors and educators is limited. As a solution, Laurea University of Applied Sciences piloted an online, LEAN-based, 5 ECTS introductory-level cybersecurity course in 2020, optimizing the use of resources based on industrial LEAN practices. The course was structured around the industry-relevant CompTIA Security+ competency framework, and instructors utilized third-party materials as much as possible, including videos, e-books, relevant internet sources, and CTF exercises. In practice, the teachers shifted from traditional content creators to instructors, focusing on pedagogical design, assessment, counseling, and tutoring. Now, four years later, this model is still in use, allowing for a deeper examination of its long-term performance. This study focuses on the same course structure as in 2020 but closely examines eight implementations offered between 2022 and 2024 implementations involving 550 students. The study applies quantitative and qualitative research approaches to relevant research metrics, including student pass rates, grade distributions, student feedback, and teacher observations. The results are promising, and the longitudinal research presented shows that LEAN-based online studies can be designed to be resource-efficient, work-life relevant, and engaging for students. However, LEAN-based online studies could lose a sense of community due to individual studies and a high automation rate. Additionally, complex tasks, like CTF exercises, still require teachers' guidance and feedback.

Keywords: Cybersecurity education, LEAN, Online learning

1. Introduction

The cybersecurity domain is suffering from a lack of a competent workforce, and ISC2 has estimated in its latest annual report that the current cybersecurity workforce gap is 4.8 million employees globally (ISC2, 2024). ISACA's latest report states that over 60% of the respondents are significantly or somewhat understaffed (ISACA, 2023). At the same time, in Finland, funding for applied sciences universities is being cut by 100 million euros between 2024 and 2028 (Maxenius, 2023). The universities of applied sciences are expected to be more efficient while maintaining a high quality of education. This phenomenon can lead to a situation where the cybersecurity domain continues to suffer from a workforce gap, and the universities of applied sciences cannot respond to increased workforce demand.

In the industry, the challenges mentioned earlier are solved by process development, and a good example is the Toyota Motor Corporation, which has applied LEAN principles for decades (Lander and Liker, 2007). The core idea is to remove process waste, develop customer value and maximize the production flow (Hines, Holweg and Rich, 2004). The same concept can be used in the learning process when the aim is to maximize teachers' working efficiency, students' learning results, and student engagement and make the learning process as smooth as possible.

Bob Emiliani, the forerunner for applying LEAN in business school courses, has excellent and promising results in his research and experiments (Emiliani, 2004, 2005). Emiliani's work inspired teachers at Laurea University of Applied Sciences, and they decided to implement LEAN to a 5 ECTS introductory level cybersecurity course based on the CompTIA Security+ framework (Kämppi and Rathod, 2020). According to Knapp & al. (2017), including certificate-based content in curricula increases industry alignment and relevancy and can enhance employability.

Four years into its implementation, this study provides a comprehensive analysis of the long-term performance of the 5 ETCS introductory level online cybersecurity course, drawing on data from eight course iterations between 2022 and 2024 and involving over 500 students. This paper uses quantitative and qualitative research methods to examine critical metrics such as student pass rates, grade distributions, and student feedback. The findings offer valuable insights into the viability of LEAN-based online education in cybersecurity, demonstrating that such models can be resource-efficient, relevant to the workforce, and engaging for students. However, the study also highlights the teacher's critical role as a counselor, especially when more complicated tasks are integrated into the course.

The article is structured as follows. Section two elaborates on related research. Section three focuses on the research methodology and research questions. Section four describes examined online course design, section five presents research results and section six discusses research findings.

2. Related Studies

Higher education institutes face many challenges, including an increased number of enrollments, increased competition, decreased government funding and high demands for work-life-relevant curricula (Jacob and Gokbel, 2018). Tatikonda (2007) states that if higher education institutes cannot solve the challenges, it can hurt the faculties' reputation and lead to students' and employers' dissatisfaction.

Researchers have proposed solutions for improving educational efficiency and quality by presenting LEAN-based teaching practices (Emiliani, 2004, 2005; Dinis-Carvalho and Fernandes, 2017; Kämppi and Rathod, 2020). Bob Emiliani, the forerunner of lean teaching, published his first results in 2004 for business school courses. He has observed that higher education had "batch-and-queue" characteristics, which set burdens for continuous study flow (Emiliani, 2004). Emiliani created a course based on LEAN principles offered during four semesters in the classroom setting. The results were promising; the overall excellence of the teacher (IDEA criteria) jumped from 3.8 to 4.8, and the overall excellence of the course (IDEA criteria) from 3.6 to 4.7. The main student feedback highlighted improved course organization, clear learning objectives, and a streamlined, focused curriculum with the course content immediately applicable to their workplace.

The second example presented by Dinis-Carvalho & Fernandes (2017) implemented LEAN principles in the classroom context for an engineering course that lasted six weeks and included 31 students. Students acknowledged the benefits of active involvement and regular assessment in their learning process. This LEAN concept of avoiding waste (in this case, time) was appreciated by students and helped ensure the efficient use of class time.

The third example by Kämppi & Rathod (2020) covers an introductory-level online cybersecurity study unit that applied the Toyota Production System (TPS) principles. The study was conducted over two semesters and involved 71 students. During the research period, which lasted two semesters, the dropout ratio was low in both implementations (5.6% and 5.7%), and over 75% of the students received better grades (grade 3 or above). Students provided highly positive feedback on the course, praising the quality of learning materials like videos and e-books that supported multisensory learning. They appreciated the structured weekly schedule, clear instructions, and rapid feedback from automated assessments.

However, despite the aforementioned promising results, academic organizations can be reluctant to adopt new innovative solutions, and they often dismiss improvement proposals made by administrators and decision-makers (Emiliani, 2005; Tatikonda, 2007). It could also be a fear of failure that prevents one from trying new methods and practices for solving existing problems (Tatikonda, 2007). Due to the growing skill gap in the cybersecurity sector, there is no room for fear of failure and new innovative teaching solutions must be presented. Cybersecurity education needs proof of evidence for the teaching practices that improve efficiency, student satisfaction and work-life relevancy, and further research for applying LEAN methods in cybersecurity education is required.

3. Research Methodology

The study was conducted as a longitudinal single case with an embedded multiple-case study approach (Yin, 2013). Yin (2013) states that the longitudinal study is suitable for cases that look at trends over time and reflect theoretical propositions set for the case study. Gerring (2007) says that a case study can gain a deeper understanding of the case being studied and demonstrate a causal argument for a hypothesis that a researcher tries to prove.

The set research question was:

- How does a 5 ECTS introductory level cybersecurity LEAN-based online course perform over time, measured by grade distribution, student retention, and quantitative and qualitative feedback?

The research was done from 2022 to 2024, and eight equivalent 5 ECTS introductory level cybersecurity course implementations were selected for study. Due to a longitudinal study approach, results show how a course that applies LEAN performs over time. The analyzed data was downloaded from LMS and the student management system. The quantitative data was analyzed in spreadsheets, and the qualitative data was analyzed with a large language model (ChatGPT 4o). The study process is illustrated in Figure 1.

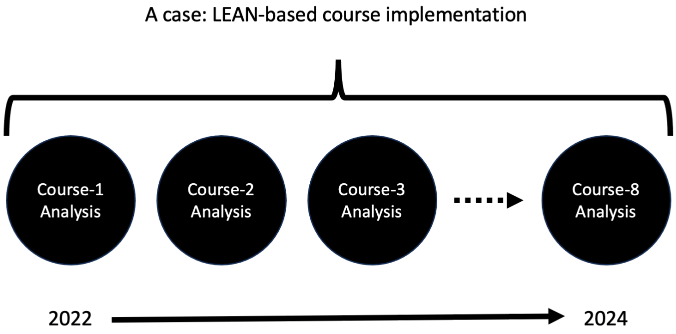

Figure 1: Research process

4. Course Design

The 5 ECTS introductory level cybersecurity course was designed according to the structure presented by Kämppi and Rathod (2020). The learning management system (LMS) has changed since 2020, and the given structure was updated based on received student feedback and teachers' observations. This section elaborates on applied LEAN principles for the course being studied. The updated course structure is presented in Figure 2.

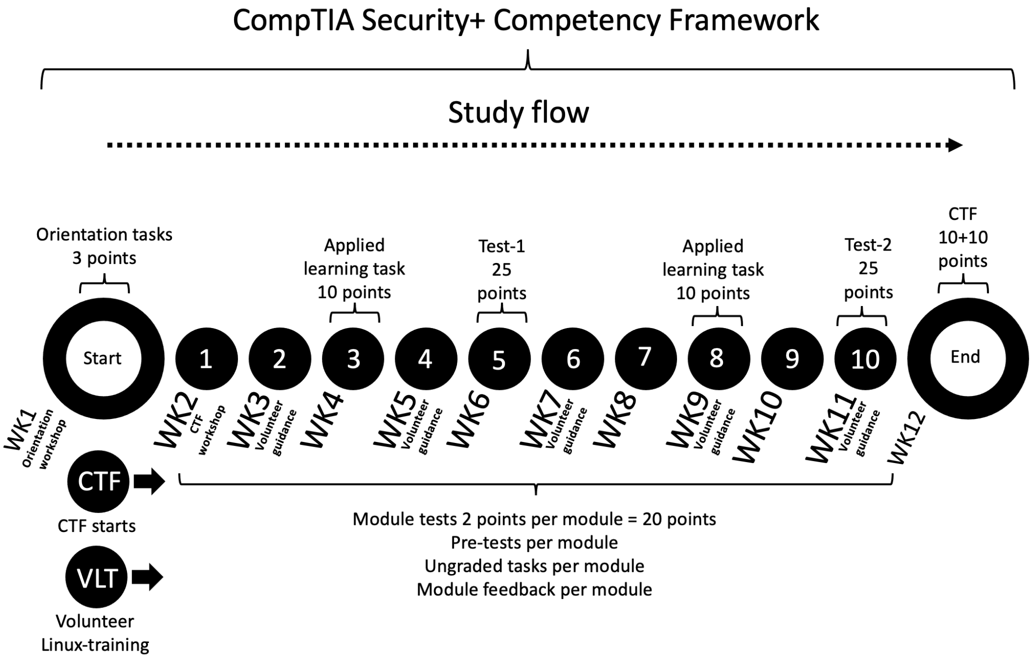

Figure 2: Course structure (adapted from Kämppi & Rathod (2020))

4.1 Leveled Production and Just-in-Time

According to Liker and Meier (2005), the first thing to do when implementing LEAN is to even out and level production. When leveling production, it is divided into smaller batches instead of bigger ones. "Just-In-Time" is closely associated with leveled production. The core idea of Just-In-Time is to minimize stock size and stock time. In practice, the target is to create a "Pull" system where waiting time is minimized, and the following process sequence pulls the outcome from the previous one and makes a flow phenomenon.

4.1.1 Content leveling

The skeleton of the course is based on implementing leveling, just-in-time and creating a pull effect (Kämppi and Rathod, 2020). The 5 ECTS introductory level cybersecurity course is 12 weeks, consisting of a week of orientation module, ten one-week study modules, and a week finishing module. Every module has a deadline and the next module is opened after completing the previous one. The students can proceed faster than deadlines require, but a 5% per day penalty for late submissions has been implemented. The Capture the Flag (CTF) exercise and volunteer Linux training are available from the beginning of the course, and students can complete them at their own pace. The volunteer Linux training aims to support students who need prior Linux skills in the CTF exercise.

Based on Comptia Security+ SY-501 certification, the content is divided among the study modules following the leveling principle. The study material, which consists of video material, e-book and external links, is divided evenly into study modules. Every module has an instructed set of videos, e-book content, and external links to study. This approach aims to support multisensory learning for different types of learners. The brief topics for the modules are presented in Table 1.

Table 1: Content leveling

Module	Content (Comptia Security+ SY-501)	
1	Cybersecurity Threats	------ STUDY FLOW ----->
2	Cybersecurity Exploits	
3	Vulnerability Assessment	
4	Network Security	
5	Security Tools	
6	Security Frameworks	
7	System Relience	
8	Identity Management	
9	Risk Management	
10	Data Encryption	
CTF	Pico CTF training platform	
VLT	Cyber Mentor videos	

4.1.2 *Pedagogical leveling*

The pedagogical leveling is made according to Bloom's taxonomy (Kämppi and Rathod, 2020). Bloom's taxonomy defines how a learning process can be designed to be progressive (Pickard, 2007). The learning objectives focus on cybersecurity terminology, concepts, threats, security controls, and best practices, so most of the learning is on remembering and understanding. However, to keep the course engaging and to meet EQF6 requirements (European Union, 2018), some learning components are placed on the levels of applying, analyzing, evaluating and creating.

In practice, there is an orientation module with orientation tasks that gain three points, multiple-choice questions in every study module that gain two points, two bigger applied learning tasks that earn 10 points each and a capture the flag (CTF) exercise that gains ten points with a possibility for ten bonus points if a student wants to put extra effort for the studies. The maximum number of points is 113 points with the bonus points. The students do an ungraded pre-test at the beginning of the study module and a self-reflection at the end of the study module as well. The application of the pedagogical leveling is presented in Table 2.

Table 2: Pedagogical leveling

	Orientation	Mod 1	Mod 2	Mod 3	Mod 4	Mod 5	Test 1	Mod 6	Mod 7	Mod 8	Mod 9	Mod 10	Test 2	CTF
Create										4				10 + 10
Evaluate														
Analyze				10						6				
Apply														

	Orientation	Mod 1	Mod 2	Mod 3	Mod 4	Mod 5	Test 1	Mod 6	Mod 7	Mod 8	Mod 9	Mod 10	Test 2	CTF
Understand **Remember**	3	2	2	2	2	2	25	2	2	2	2	2	25	
	-----------> S T U D Y F L O W ---------->													

4.1.3 Teachers' work leveling

Teachers' work is planned carefully according to the course design to avoid unexpected peak load (Kämppi and Rathod, 2020). As synchronous online sessions, teachers give a course orientation workshop, a CTF orientation workshop and biweekly volunteer counseling. In asynchronous tasks, teachers are responsible for assessing, counseling and submitting biweekly summaries for students' reflection. When the sessions and tasks are scheduled carefully, teachers can allocate course-specific working time in their calendars and commit to a just-in-time approach.

4.2 Waste Reduction

The principles of waste reduction are adopted from Kämppi & Rathod (2020) with minor improvements. The objective is to focus resources on pedagogical development, guidance and assessment, not creating materials. To avoid overproduction, Fair Use video material (Messer Studios, 2018; Adams, 2019), a commercial e-book (Dulaney and Easttom, 2017) , and a Fair Use third-party CTF platform (Chapman, Burket and Brumley, 2014) are used. To create a pull effect and minimize waiting, unnecessary transport, over-processing, excess inventory and unnecessary movement, all course-related instructions, materials and practices are implemented in the LMS. In practice, students and teachers have a single platform for course-related items. All waste reduction-related practices are described in Table 3.

Table 3: Waste reduction (adapted from Kämppi & Rathod (2020))

Waste	Characteristics
Overproduction	Use of third-party learning material and CTF platform
Waiting	Automated late return penalties, Use of automated assessment, Prompt feedback, Clear scheduling, Pull
Unnecessary transport	Points tracked in LMS, E-material including videos and e-book
Over processing	Automated late return penalties, Scheduled counselling sessions, Clear communication norms
Excess inventory	Automated assessment, Automated late return penalties, Teacher's work schedule
Unnecessary movement	Distance learning, Scheduled counselling sessions
Defects	Student feedback, Teacher's observation
Unused employee creativity	Student feedback and improvement proposals, Teacher's analysis

4.3 Visual Management

Lander and Liker (2007) promote visual management to facilitate a shared understanding of the current situation. LMS offers various visual management tools for students and teachers (Kämppi and Rathod, 2020). For teachers, LMS provides the possibility to follow students' point gain with grids, statistical user behavior charts and charted summaries for the module-based reflections. Students can follow their progress and plan their studies when all information is available via a single user interface.

4.4 Build-in Quality

Build-in quality is one of the key principles of the LEAN process (Sugimori *et al.*, 1977; Liker and Meier, 2005). The foundation of the build-in quality is that the defects in the process are fixed as soon as possible and prevent defective products from proceeding in the production line. In the course-specific context, teachers should fix defects such as incorrect answers to multiple choice questions, incorrect dates in the scheduling, or expired links to external materials as soon as possible (Kämppi and Rathod, 2020). Kämppi and Rathod (2020) state when students see that the teachers are responding to the defects, they are more willing to contact teachers whenever a defect occurs.

4.5 Standardized Processes

Liker and Meier (2005) state in their book that "Standardization is critical in limiting variation in the process and achieving efficient production in a timely manner." In the course that applies LEAN principles, all tasks are scheduled carefully; study practices remain the same during the course, assessment criteria are public and transparent, communication practices between teachers and students are clear, and conditions for unexpected events (e.g., for sickness) are expressed clearly (Kämppi and Rathod, 2020). All practices and information are available in the LMS workspace.

4.6 Continuous Improvement

Tatikonda (2007) says in his paper, "What gets measured gets improved", which applies to course implementation well. Tatikonda (2007) proposes a scorecard model defining measures for a specific LEAN process. The measures are tightly coupled with the Plan-Do-Check-Act (PDCA) model, which gives cyclic and structured improvement tools (Sokovic, Pavletic and Pipan, 2010). In the educational environment, data from LMS and the student management system can be fetched and data that can be processed to process-specific measures. As an example of quantitative measures, grade distributions, drop-out rates, engagement rates, content quality and course feedback metrics can be calculated (Kämppi and Rathod, 2020). As qualitative measures, module-specific and course-specific open feedback data can be collected (Kämppi and Rathod, 2020).

5. Results

This section focuses on the results of the study, including the course demography, course grade distribution, quantitative course feedback and qualitative course feedback.

5.1 Demography

The course being studied is offered at the beginning of the second study year for four degree programs in Laurea, Digital Services Development (Finnish and English degree programs) and Cybersecurity (Finnish and English degree programs). Additionally, a limited number of seats for other target groups are available. Students in the Digital Services Development degree program focus on developing software, applications and services according to the Software Developing Life Cycle (SDLC) framework. The Cybersecurity degree program includes studies in cybersecurity, including management and technological aspects. Despite the different specializations, all degree programs have the same core ICT studies during the first study year. During the study period, eight course implementations were offered during the years 2022-2024. Due to the higher intake in the Digital Services Development degree programs, almost 55% of students belong to that target group. The cybersecurity degree programs were launched in the autumn of 2021 with a lower yearly intake, which explains the lower number of participants (34%). Other target groups had a relatively low share, with 11,1%. The details are presented in Table 4.

Table 4: Demography

Year	Semester	Enrolments	Fin Digi	Eng Digi	Fin Cyber	Eng Cyber	Sec Man	Open UAS	Exchange	Other
2022	Spring	48	40	3	0	0	1	4		
2022	Summer	29	10	6	2	7	1	3		
2022	Autumn	76	42	5	1	19	0	1	6	2
2023	Spring	79	33	2	33	3	0	6	2	
2023	Summer	70	16	10	23	11	0	9		1
2023	Autumn	85	39	3	22	13	0	2	5	1
2024	Spring	108	56	8	37	5		2		
2024	Summer	55	23	6	4	7		12		3
Summary		550	259	43	122	65	2	39	13	7
Share			47,1%	7,8%	22,2%	11,8%	0,4%	7,1%	2,4%	1,3%
				54,9%		34%				11,1%

5.2 Grade Distribution

Table 5 shows the enrolments, the number of students who started the course and the grade distribution. An average of 87,4% of enrolled students began the course, indicating that the course proved to be enjoyable from the beginning. Of the students who started the course, on average, 77% got a grade of 3 or better with a scaling of 0-5. Lower grades, from 2 to 0, got an average of 23% of students while the drop-out ratio was 13,1% average. A low drop-out ratio and good grades indicate that the course design engages and motivates students, and they put effort into their studies.

Table 5: Grade distribution

Year	Semester	Enrolments (n=550)	Started (n=482)	Grade 5	Grade 4	Grade 3	Grade 2	Grade 1	Grade 0	Pass %
2022	Spring	48	97,9%	34,0%	25,5%	19,1%	4,3%	4,3%	12,8%	81,2%
2022	Summer	29	86,2%	60%	0,0%	12,0%	8,0%	4,0%	16,0%	84%
2022	Autumn	76	92,1%	35,7%	24,3%	17,1%	10,0%	1,4%	11,4%	88,6%
2023	Spring	79	86,1%	39,7%	7,4%	26,5%	8,8%	5,9%	11,8%	88,3%
2023	Summer	70	88,6%	41,9%	21,0%	12,9%	4,8%	4,8%	14,5%	85,5%
2023	Autumn	85	89,4%	28.9%	31,6%	17,1%	11,8%	3,9%	6,6%	93,4%
2024	Spring	108	88,0%	35,8%	21,1%	16,8%	6,3%	6,3%	13,7%	82,3%
2024	Summer	55	70,9%	28,2%	25,6%	23,1%	5,1%	0,0%	17,9%	82,1%
Average			87,4%	39,3%	19,6%	18,1%	7,4%	3,8%	13,1%	85,7%
StDev			7,7%	10,1%	10,5%	4,8%	2,7%	2,1%	3,4%	4,2%

5.3 Quantitative Course Feedback

At the end of the course, students could give course feedback. Coherent feedback data was available for five course implementations. The answer rates are low, but clear trends can be seen in the answers over time. The answer scale for questions was one to five, with five being best and one worst. Both competence-related questions got good feedback (Q1=4,73 and Q2=4,58), and it can be associated with a good course design and relevant course materials. The result also proves that an industrial certification framework, in this case, CompTIA Security+, can be applied successfully in the academic environment. According to feedback, selected working methods activated students (Q3=4,65), they got enough guidance (Q4=4,30), and used working methods supported competence development (Q7=4,58). The Q8 (4,26) indicates that the overall workload is aligned with the credits received, and content and pedagogical leveling works well. The feedback related to feedback on development (Q5=3,82) and the sense of the community (Q6=3,86) got the lowest scores. The high assessment automation rate and individual online studies explain the weakest scores. The details are presented in Table 6.

Table 6: Quantitative course feedback

	Summer 2022 (n=9)	Autumn 2002 (n=16)	Spring 2023 (n=10)	Autumn 2023 (n=14)	Spring 2024 (n=9)	AVG	STDEV
Q1. My competence has developed according to the goals of the study unit.	4,89	4,75	4,8	4,79	4,44	4,73	0,17
Q2. The study unit has improved my skills and competencies needed in working life.	4,44	4,63	4,6	4,79	4,44	4,58	0,15
Q3. I have worked actively to develop my competence.	4,78	4,5	4,7	4,71	4,56	4,65	0,12
Q4. I have received enough guidance to develop my competence.	4,22	4,56	4,7	4,14	3,89	4,30	0,33
Q5. I have received feedback on my development.	3,56	N/A	4	3,57	4,13	3,82	0,29
Q6. There was a sense of community that supported learning.	3,78	N/A	4	3,86	3,67	3,83	0,14

	Summer 2022 (n=9)	Autumn 2002 (n=16)	Spring 2023 (n=10)	Autumn 2023 (n=14)	Spring 2024 (n=9)	AVG	STDEV
Q7. The working methods have supported the development of my competence.	4,78	4,75	4,5	4,64	4,25	4,58	0,22
Q8. The workload was appropriate compared to the credits received.	4	4,13	4,7	4,14	4,33	4,26	0,27
AVG	4,31	4,55	4,50	4,33	4,21		
STDEV	0,5	0,23	0,32	0,47	0,30		

5.4 Qualitative Course Feedback

The students appreciated a clear and structured course organization with a logical progression, which is well aligned with the philosophy of LEAN, creating a flow. The ability to proceed at their own pace (Just-in-Time) was valued, especially for students with busy schedules. The combination of learning resources, including high-quality video material, course book, external links, quizzes, applied tasks and CTF helped students to connect theory to real-world scenarios. This indicates that the content- and pedagogical leveling are used accordingly and help students achieve desired learning objectives. The CTF was especially mentioned as a motivating and rewarding learning experience.

Most improvement proposals concern content, pedagogical implementation, tight scheduling, and the complexity of CTF. Some students reported that the content had an overwhelming amount of terminology, and they had difficulties understanding cybersecurity terminology. The second issue refers to outdated content, an expired CompTIA Security SY-501 certificate framework and a few contextually outdated external links. The tight weekly scheduling was challenging for some students but was also appreciated because it kept the study flow on. The main pedagogical issues concern hands-on training and the CTF. Some students would like to have more practical tasks and at the same time, some students reported that the CTF is too demanding without sufficient guidance. Notably, there were no improvement proposals regarding course structure or organization.

6. Conclusion

After three years and eight LEAN-based 5 ETCS introductory level cybersecurity course implementations, one can say that the results are promising. The results are well-aligned with Emiliani's (2004) study, where the results remained good after the first LEAN-based course implementation. In Emilani's study, the overall excellence of the course with IDEA (2004) criteria varied from 4,1 to 4,7 and the average of the measures in this study ranged from 4,31 to 4,55. The measures in the IDEA (2004) criteria and feedback criteria applied in this study are unequal. Still, the results indicate that student satisfaction remains good in the LEAN-based course implementations over time.

Causalities can be found between LEAN principles and results. The fundamental ideas of LEAN are creating flow and pull, keeping students engaged, resulting in good grades (over 75% got a grade 3 or better), and a low drop-out ratio (13,1%). The key principles, content and pedagogical leveling enable a smooth study process with diverse study material and assignments covering all levels in Bloom's taxonomy. The waste reduction, especially using third-party study materials, frees teachers' time for course design, improvement counseling and assessment work. Other applied LEAN principles, including visual management, build-in quality, standardization, and continuous improvement, are necessary to keep course quality high, which is visible in continuous good feedback scores. The study also shows that the cybersecurity framework fits well for diverse target groups, not only cybersecurity students.

The main improvement ideas based on quantitative and qualitative feedback concern outdated content, limited feedback, a sense of community and CTF complexity. The applied CompTIA Security+ framework should be updated to the latest one, but the online learning environment sets some limitations for creating a sense of community. Due to the high number of students, teachers should think carefully about how they use their resources to give feedback without overwhelming themselves. According to the LEAN principle, to avoid over-production and over-processing, teachers could organize a few more online workshops for CTF, offering the possibility of giving feedback and working in groups with CTF challenges in teachers' guidance.

The study shows that certification-based cybersecurity competency frameworks and third-party materials can be successfully applied in higher education for different target groups when the LEAN-based study process is designed accordingly. The proposed model could be a part of the solution if a higher education institution wants to develop its curricula as industry-relevant by being associated with compliant third-party certification competency frameworks and materials. The model frees the teacher's time for pedagogical work and student support instead of creating materials, and students benefit from up-to-date industry-relevant content and an engaging learning experience. Ultimately, when students are engaged in cybersecurity studies, they could find cybersecurity a viable option for their profession and ease the global workforce gap.

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