UNIVERSITÄT PADERBORN
Die Universität der Informationsgesellschaft

Fraunhofer IEM

Master Thesis

Identifying suitable learning formats for Systems Engineering

Submitted By: Sachin Kumar
Matr.-Nr. 6906625

Supervised By:

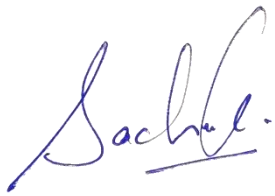
Ulf Könemann
Lynn Humpert
Prof. Dr.-Ing. Roman Dumitrescu
Dr.-Ing. Sebastian von Enzberg

Paderborn, 17.11.2023

FRAUNHOFER-INSTITUT FÜR
ENTWURFSTECHNIK ECHATRONIK IEM
Zukunftsmeile 1
D-33102 Paderborn

Affidavit

I hereby declare in lieu of an oath that I have prepared this thesis independently and without unauthorized outside help, that I have not used any sources or aids other than those indicated, and that I have marked as such any passages taken verbatim or in substance from the sources used.



Paderborn, 17.11.2023

Place, Date

Signature

Abstract

The thesis systematically explores the suitability of different learning formats to enhance systems engineering competencies. It identifies the features of these learning formats, along with their respective advantages and limitations. Additionally, it identifies systems engineering qualification characteristics and establishes connections between these characteristics, systems engineering competencies, and defined learning formats.
A method has been developed to enable the application of the learning formats in the planning of SE qualifications. The method assists in prioritizing learning formats by considering their advantages and disadvantages and aligning them with the individual's requirements.

Table of Contents Page

Appendix **Page**

1 Introduction

In this chapter, first, “Motivation” will be provided; it offers insights into the need for systems engineering, emphasizing its necessity and application. Furthermore, the importance of a Systems Engineering (SE) qualification has been shown. The second subchapter, “Structure of Thesis,” briefly introduces each chapter defined in this documentation.

1.1 Motivation

Goods and services are shifting from mechanical products to smart, cyber-physical systems shaped by dynamic networking, autonomy, and sociotechnical integration. Paired with this phenomenon is a growing spectrum of internet and platform-based services, along with the accessibility of substantial volumes of data. These factors generate favourable prospects for inventive and data-driven services (smart services). Fulfilling future system requirements cannot be solely attributed to any specialized discipline. Instead, it required the cultivation of innovative perspectives that encompass interdisciplinary approaches to addressing these systems. Central to this approach is integrating best practices that facilitate increased stakeholder interaction and collaboration in developing such systems. These systems require close cooperation between various specialist disciplines and call for a need for interdisciplinary SE to deal with the complexity of such projects and companies [DAR21, p.19]. As systems become larger and more complex, engineers are required to integrate a diverse range of components and subsystems, often developed by different teams or organizations. In addition, there is a potential for an increase in the customization of systems from both customer and user perspectives, which further adds to the complexity of systems engineering [DAR21, p.25]. To address the increasing complexity of planning, development, production, and operation of systems, there is a growing need for interdisciplinary SE to integrate and coordinate various fields. SE offers a comprehensive solution that covers the entire development process and holds great promise for creating complex technical systems [DAR21, p.57].

The success of such projects (Advanced Systems) in systems engineering depends on the engineer’s proficiency and ability to apply the necessary competencies effectively. Competency areas in systems engineering can be categorized into professional, systems engineering management, technical, and integrating competencies [Int21, p.19].

The development and assessment of these competencies are essential to improve the practice of SE. INCOSE provides a framework for the competencies required in systems engineering, comprising 36 different competencies. The framework helps practitioners and stakeholders identify the critical knowledge, skills, abilities, and behaviors that are necessary for achieving effectiveness in systems engineering [BGD+18, p.13].

A study by STÜTZEL BENNO [Stü21, p.18], suggests the progress in systems engineering introduction in the organization. The study surveyed participants whose companies were in the process of implementing systems engineering and assessed the overall progress. The results showed that up to 40% of the companies were categorized as beginners, 40% to 80% as intermediate, and over 80% as experts. Following the logic, 64% of respondents describe their company as starters, 29% as advanced, and only 7% as professionals. The study highlights significant opportunities for companies to enhance the qualifications of their employees. The need for qualification is particularly relevant as a majority of the companies are either in the process of introducing systems engineering or are in the advanced phase. These companies still require guidance to fully integrate systems engineering practices into their operational environments.

1.2 Structure of the thesis

The thesis is organized into several chapters, each serving a distinct purpose in achieving the research objectives and providing a comprehensive understanding of the topic. The following outlines the structure of the thesis:

- In Chapter 1, the thesis offers an introduction with subtopics, including thesis motivation, where key points are mentioned to suggest why this topic has been considered and the current advancements in systems engineering. It also provides a brief insight into the topic of qualifying employees for changing needs. Following that, the structure of the thesis is defined.
- Chapter 2 is divided into two subchapters. The first subchapter involves a formal analysis of the problem by examining various studies that explain the inefficiency of learning programs, changing the mindset of the employees, along with other key insights. The second subchapter considers those problems and defines the "Problem Statement," which explains the goal and sub-goals of the thesis by further dividing them into the requirements and field of action.
- In Chapter 3, "State of Art," provides a brief overview of foundational aspects of the research topic. It includes topics such as "Systems Thinking," "Model-Based Systems Engineering," "Learning Formats," "Competencies," and more. The second subchapter, "Field of Action," explains the thesis's objective, where objectives are divided into multiple requirements, and finally, the chapter concludes with a summary.
- Chapter 4 of the thesis consists of "Solution Design." This chapter presents the solution design for the field of actions defined in Chapter 3.2. It defines the learning formats in detail by narrowing down the suitable qualification characteristics for SE and explaining these characteristics and the learning formats matrix. The chapter also show the findings for the field of action, such as the creation of posters and providing detailed explanations of their parameters. Additionally, this chapter addresses the execution of the SE competency and SE characteristics matrix, the mapping of SE

characteristics to the learning format, and the final inference, which suggests suitable learning formats for specific SE competencies. The chapter finally ends by explaining the tasks added to the process methods initially defined by KÖNEMANN et al.

- Chapter 5 entails the evaluation of the previously defined approaches, including validating the LF posters and systems engineering qualification characteristics. It shows the validation process and adaptation after every expert review and shows various versions of the evaluated posters and characteristics.
- Chapter 6 encapsulates the conclusion of the thesis, summarizing the essential findings and contributions. Furthermore, the subchapter outlines potential future research and exploration within the chosen research topic.

2 Problem analysis and statement

In the “Problem Analysis” subchapter information is gathered from various sources to analyze and understand the problem, enabling the identification and breakdown of the problem into its constituent subproblems. The goal is to provide an understanding of the problem’s dimensions. Once the problem is analyzed and the contextual details are obtained, the next step is to define it. While defining the problem, for clarity, it is divided into three fields of action, and subsequently, it is further diverged into various requirements in the “Problem Statement” subchapter.

2.1 Problem analysis

The proposed research aims to address the problem of identifying the most suitable learning formats for systems engineers. Currently, there is a lack of methods for recommending the learning formats, which can result in inconsistencies and gaps in knowledge and skills. According to one study in [DAR21, p.115], the training program studying content may not be effective due to inadequate learning content or not being tailored according to the needs of the company. The incorporation of system competence education into foundational courses is needed. The universities have limited flexibility due to conservative structures, so it is necessary to engage in collaborative efforts with companies [DAR21, p.114]. Furthermore, collaborating with engineers currently pursuing their studies is not a feasible option for many companies. To address the inefficiency of programs and the requirement of competencies, the research will aim to systematically evaluate existing learning programs and recommend structured learning formats tailored to individual or company requirements. According to JACOBS et al., traditional educational qualifications are losing significance due to new technologies and workflow trends in various industries [JKS22, p.53].

One key question in the companies is how they can regularly assess their current and future systems engineering competencies as well as determine the required training once these competencies are identified. They must analyze competency requirements in practice and available literature [JKS22, p.13]. In order to fulfill these requirements, employees are expected to enhance their core competencies.

In the context of change management in organizations, one of the critical issues concerns the challenge of shifting the mindsets of both employees and institutions. Despite its significance, this aspect is frequently overlooked or undervalued by management during strategic planning [Jos21]. The mindset relies on elevating personal and professional skills. According to the research conducted by SANDMEIER et al., companies need to recognize that the long-term success of a person’s continued training can be significantly enhanced [SHG18, p.15].

Effective communication and continuous learning are crucial for individuals to develop and change their mindsets [Jos21]. Therefore, implementing appropriate learning formats is essential in workspaces. These formats enable people to communicate, collaborate, and engage in continuous learning activities while on the job. Through regular interactions and sharing of experiences, individuals can challenge their existing beliefs, learn from one another, and develop new perspectives. To empower a more significant number of systems engineers with robust multi- and transdisciplinary competencies, there is a need to establish a pipeline encompassing education, training, mentoring, and lifelong learning initiatives [DAR21, p.71]. There is an increasing need for life-long learning (for SE individuals), and according to VANDEWALLE, it was observed that individuals who embraced a growth mindset exhibited greater efficacy in terms of acquiring course concepts, discovering effective strategies, and attaining superior outcomes [Van12, p.303].

The proposed research will not only identify suitable learning formats for systems engineers but also establish criteria to determine when specific programs should be used or limited based on SE competencies.

2.2 Problem statement

This chapter outlines the problem statements of the thesis, which are based on the learning formats for systems engineers. The literature recommends various learning formats, as cited in sources such as [Zeu16], [MGV+16], [KKK+23], [Lin22-ol; Pro21], [TG14], and more. Furthermore, the literature on learning types, as exemplified in VESTER'S work "*Denken, Lernen, Vergessen*" [Fre98], was further analyzed by the MAIKE LOOß in "*Types of Learning*" [Loo01]. According to JOSHI [Jos21], continuous learning is needed to change the mindsets of employees. Professional growth is a continuous learning process that enables individuals to acquire the knowledge, skills, and abilities needed to cope with changing demands for vocational proficiency throughout their careers [BG99], [PLN].

As previously mentioned in Chapter 2.1, the **goal** of the thesis involves identifying appropriate learning formats that can enhance the skills of systems engineers. It also guides and recommends these programs to companies that are seeking to improve the competency of their systems engineering team. The selection of a format depends on several factors, including the level of effort required and the number of participants to be trained, among other considerations. It is crucial to understand these factors to make an informed selection of the most appropriate formats.

A crucial step in the process of recommending learning formats to individuals or organizations is first to identify the various major formats available that can be structured according to specific requirements. Therefore, the **first sub-goal** of this thesis is the identification of learning formats. There is a lack of an overview of learning formats, so the first requirement of the master thesis shall provide an overview of learning formats which can be used for developing competencies. The characteristics of the learning formats are

not clearly presented, leading us to the second requirement, i.e., define and conduct a comprehensive investigation of different learning format features, such as the duration, learning outcomes, and others. Additionally, the thesis will explore the most suitable parameters for introducing these programs.

Given the rapidly changing and complex nature of the field, the skills and qualifications of system engineers are critical to the development of tomorrow's products and services [DAR21]. Limited literature is available that defines the learning formats for systems engineering competencies. Therefore, the **second sub-goal** of this thesis is to identify the criteria for selecting learning formats in systems engineering so that up-to-date knowledge would be transferred to the systems engineers. The third requirement for the thesis is to identify the qualification characteristics for systems engineers and explain when and for whom a specific format should be chosen to maximize learning outcomes. The connection between the learning formats and SE competencies is rarely viewed in the literature, which brings us to the fourth requirement of the thesis, i.e., to find out the link (if any) between the SE competencies and identified learning formats. Additionally, the thesis will provide guidelines on when a particular program may not be suitable for professionals (learners) in this field. The thesis will explore the linking of systems engineering competencies (defined by INCOSE and adapted by KÖNEMANN et al.) with the identified systems engineering competencies.

Many learning resources are accessible nowadays, but the question lies in crafting appropriate learning arrangements tailored to the specific audience and their requirements, all while aligning with the resources at hand. The research made by BALDWIN and FORD and further explained by PROHASKA [Pro21, p.25] that merely 10 to 30% of participants effectively apply their acquired knowledge. Considering the expenses associated with numerous trainings, this marks an exceptionally low percentage. Briefly engaging with each participant to discuss goals and expectations prior to additional training would result in better outcomes of training [Pro21]. A study conducted by BRIAN et al. [BFB+10] in "Transfer of Learning" shows the impact of predictive factors (e.g., trainee characteristics, work environment) on the transfer of training but lack of knowledge about learning arrangements of the training. The **third sub-goal** of this thesis is to create and plan learning arrangements to maximize the benefits of the training. The fifth requirement of the thesis involves an overview of the planning of identified LFs for learning arrangement. The information is split into various literature about which elements to include to plan a learning format effectively. That leads to the sixth requirement, where the thesis shall give an overview of different learning elements that can be used in planning identified learning formats to ensure effective knowledge transfer and skill development. The last requirement is that the thesis considers the maturity of the implementation of SE in companies and accordingly defines the archetypes of SE qualifications.

Figure 2-1 summarises the list of requirements as explained above in the form of goals and sub-goals. Requirements (R) are defined as sub-goals from "R1, R2, … R7" and three fields of actions on the right side as goals.

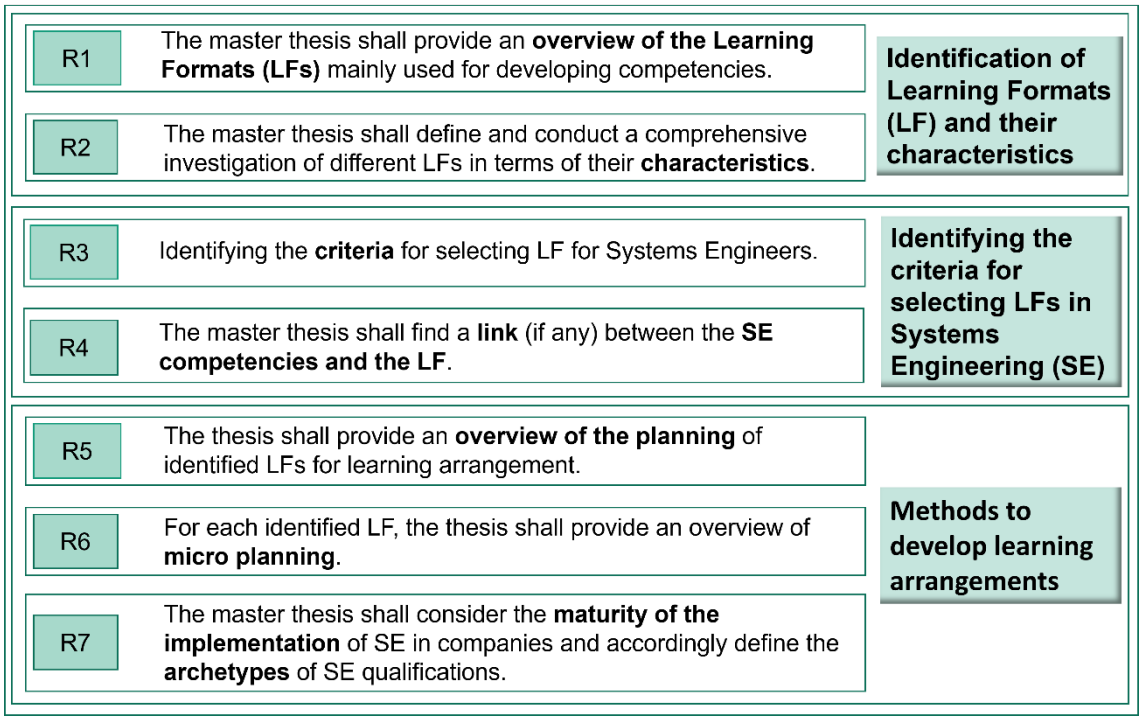


Figure 2-1: List of Requirements (R) and three Fields of Actions

3 State of art

The “State of the art” chapter delves into various aspects of SE qualifications and competencies. It starts by laying down the fundamentals and the essence of Systems Engineering. Introducing the concept of “Model-Based Systems Engineering,” followed by the exploration of qualifications and different learning formats. Research has been carried out to determine the criteria suitable for SE qualifications. The chapter then delves into learning types and the diverse fields of action within SE. Furthermore, the chapter describes learning formats and presents the “Systems Engineering Competency Framework,” defined by INCOSE. The chapter concludes by summarizing the comprehensive mapping of requirements with the established learning formats, encapsulating the critical insights of the entire discussion.

3.1 Fundamentals

Chapter “Fundamentals” delves into various crucial aspects of systems engineering and its foundational principles. It covers a comprehensive range of subchapters, including “Systems Engineering,” which introduces the core concept; “Model-Based Systems Engineering,” which explores the integration of models into the process; “Qualifications,” focusing on the necessary skills; “Learning Formats,” presenting different formats for qualifications; “Characteristics Suits to Systems Engineering Qualifications,” discussing appropriate criteria alignment; “Competency,” emphasizing required skills and expertise; and finally, “Learning Types,” exploring the diverse approaches to learning within the realm of systems engineering. This synthesis of subchapters provides a well-rounded understanding of the fundamental elements and principles that underpin the discipline of systems engineering.

3.1.1 Systems Engineering (SE)

To understand the subject of SE, one must possess knowledge of systems and their boundaries, along with an understanding of systems thinking. Both topics are covered in the subchapters below.

3.1.1.1 Systems

To establish the concept of systems engineering, it's necessary to examine the definitions of systems as provided by INCOSE and ISO/IEC/IEEE. As per these organizations, a system denotes a unified arrangement of components, sub-systems, or assemblies working together to achieve a specified goal. These components encompass a broad spectrum, such as products (hardware, software, firmware), processes, individuals, information, methodologies, infrastructure, services, and supplementary support elements (as defined by INCOSE). It is characterized as a synergy of interconnected components structured to fulfil one or more predefined objectives, according to the ISO/IEC/IEEE 15288 definition [Int15].

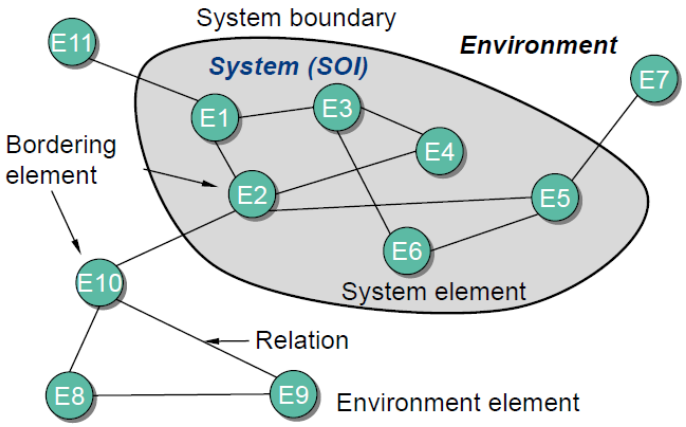


Figure 3-1: System of interest with the system boundaries

- In Figure 3-1*:*

1) E1, E2, … E11 are the elements of the system that cannot be resolved further.

2) The "Relation" linking various components can also be referred to as impact-potential. One category of these connections consists of the pathways through which materials, information, and energy move.

3) A system boundary is a more or less randomly or intentionally chosen boundary between a System and its environment. The system boundary defines the System of Interest (SOI) [HWF+19, p.5].

3.1.1.2 Systems Thinking

According to [HWF+19, p.3], systems thinking refers to a way of thinking that facilitates a better understanding and designing of complex phenomena (referred to as systems).

Systems thinking encompasses:

- View the whole system as open and interactive.
- Defines the terms of complex entities and their relations.
- Model-driven methods for visualizing real complex phenomena without the necessity of excessive simplification.
- Strategies that foster holistic thinking.

3.1.1.3 Systems Engineering

According to HABERFELLNER et al., systems engineering represents an interdisciplinary strategy and approach aimed at facilitating the successful realization of systems. It centers on the early determination of customer requirements and essential functionalities during the developmental phase [HWF+19].

It involves capturing requirements, followed by the synthesis of design and validation of the system, all while addressing the comprehensive spectrum of challenges: operational aspects, costs, schedules, performance, training and support, testing, manufacturing, and disposal. This methodology integrates diverse disciplines and specialized groups into a collaborative endeavor, constituting a structured developmental process that progresses from concept creation to production to operational implementation (INCOSE, 2004).

Systems engineering takes into account the business and technical prerequisites of all stakeholders, with the ultimate objective of delivering a high-quality product that aligns with user needs (INCOSE, 2004).

Defining the roles is significantly important while introducing the systems engineering within an organization. There are 12 roles defined by SHEARD [She96, p.2] for systems engineers, though the allocation of specific responsibilities to these roles remains a fluid consideration [DAR21, p.70], However, there exists a distinct understanding of the essential skills and qualifications necessary, along with suitable educational and training for each role.

3.1.2 Model-Based Systems Engineering (MBSE)

The concept of Model-Based Systems Engineering (MBSE) is introduced through an initial explanation of model-based engineering, which emphasizes the central role of models. After that, the subchapter ends with a description of MBSE and its advantages.

3.1.2.1 Model-Based Engineering (MBE)

Model-based engineering (MBE) aims to describe essential aspects of a product being developed using models. When it comes to creating complex systems during product development, digital models are used for testing and improvement.

Technologies like CAD are commonly used for tasks involving 3D shapes, MATLAB is used for simulation for optimization or function testing, etc. In addition to these well-known methods, system modeling is becoming increasingly important. Also, MBE focuses on developing, improving, and testing complex systems using interdisciplinary models.

3.1.2.2 Model-Based Systems Engineering (MBSE)

MBSE is defined by the INCOSE Systems Engineering Vision 2020 (2007) as the formalized application of modeling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases [Int15, p.189].

MBSE stands as the primary method for future product development. The central emphasis lies on the system model, encompassing crucial product details and persistently applied across the entirety of its life cycle.

It enhances the process of analyse, capturing, sharing, and managing the information for the product. Below are the benefits once MBSE is executed [Int15, p.189]:

- Better communication among the people working on development.
- Easier management of complex systems by looking at a system model from different angles and understanding how changes affect it.
- Higher quality products because there is a clear and exact model of the system, which can be checked to make sure it all makes sense and is complete.
- More effective recording and reuse of information by using standard methods and the built-in ways models work.
- Teaching and learning the basics of systems engineering becomes more straightforward with a clear and exact representation of the ideas.

The system model needs to include all the essential properties of the system that are required in order to understand and build it. In the MBSE approach, a lot of information is put into the system model(s) while not overloading it unnecessarily. The system model acts as a glue between all the models, including the model focusing on development, risk minimization through structured approaches, reducing complexity, and finally, the verification and validation model.

3.1.3 Qualifications

According to the European Qualification Framework (EQF), a formal evaluation and validation process outcome occurs when a recognized entity, such as an educational institution or certification body, confirms that an individual has achieved specific learning outcome standards. This formal result is a crucial step in the qualification process, indicating that the individual possesses the knowledge, skills, and competencies aligned with established educational and vocational standards. This recognition is valuable, enabling individuals to demonstrate their qualifications to employers, institutions, and other stakeholders.

3.1.3.1 Qualifications in Systems Engineering

Systems engineering is an interdisciplinary approach to designing, integrating, and managing complex systems throughout their life cycles. Qualifications are essential to build tomorrow’s products and services [DAR21, p.107]. Qualifications can vary based on the specific job role within systems engineering, whether focused on requirements analysis, architecture design, integration, verification and validation, or project management.

It's important to note that systems engineering is a dynamic field where continuous professional development is essential to stay up to date with the latest methodologies, technologies, and best practices. The evolution of advanced systems requires the acquisition of fresh competencies and qualifications within established domains. This evolution also entails the seamless integration of additional departments [DAR21, p.54].

There are qualification programs that are specific to the companies or individuals for systems engineering or for the industries that are introducing the SE. Qualification standards should be closely aligned with implementing SE. This is essential because achieving proficiency in systems engineering presents a significant challenge for companies. The initial level of implementation greatly influences the objectives of the qualification process. Suppose the qualification aims to apply SE in practical scenarios. In that case, it becomes crucial to ensure the availability of essential prerequisites, including processes, methods, tools, and sufficient time and resources. Otherwise, the trainees are bound to experience frustration.

3.1.4 Competency

While introducing SE in the organisation or the employees qualifying for the SE, they have to identify their personal skills and knowledge. The depth of the should be identified such that respective training can be given to fill the gap. According to INCOSE [Int15, p.177], Competency (in terms of SE) can be defined as the ability of employees relative to SE tasks—also, individual competency to the organizational, system, and operational capabilities. The term competence has a meaning, something like ability, and skill competencies are "specific skills, knowledge and metacognitive knowledge that can be learned in principle, which allow [..] requirements in specific [..] work environments to be mastered [KFL+01]".

INCOSE (International Council on Systems Engineering) has created a Systems Engineering (SE) Competency Framework [Int15, p.23]. The framework is designed to help employees assess their skills and determine whether they need additional training, coaching, or new job responsibilities to address any skill gaps identified in the assessment. Employees can take a closer look at their abilities and make informed decisions on how to enhance them.

3.1.4.1 Competency framework categories by INCOSE

The five categories are further defined into the 36 competency areas of systems engineering. It directs professionals and interested groups in recognizing the essential knowledge, competencies, skills, and behaviors necessary for effective systems engineering [BGD+18, p.26].

3.1.4.2 Adapted framework categories by KÖNEMANN et al.

In the adapted competency framework, competencies are redesigned and clustered for better understanding. The 16 competencies have been recognized as integral components of the Core, Social/Personal, and Technical Competencies.

In the thesis, we reference the competency framework as defined by KÖNEMANN et al. [KWA+22, p.5] to facilitate comprehensive comparisons, mappings, and analyses in various aspects.

3.1.4.3 T-Shaped competency model

Based on the results of the survey made by DUMITRESCU [DAR21, p.111] in "ASE: Engineering in Germany," a T-shaped model has been constructed, as shown in Figure 3-2. The goal of the survey is to find the skills required in engineering in the future. In the T-shaped model, a distinction is made between the generalist and the specialist based on the specialization and basic understanding of the disciplines.

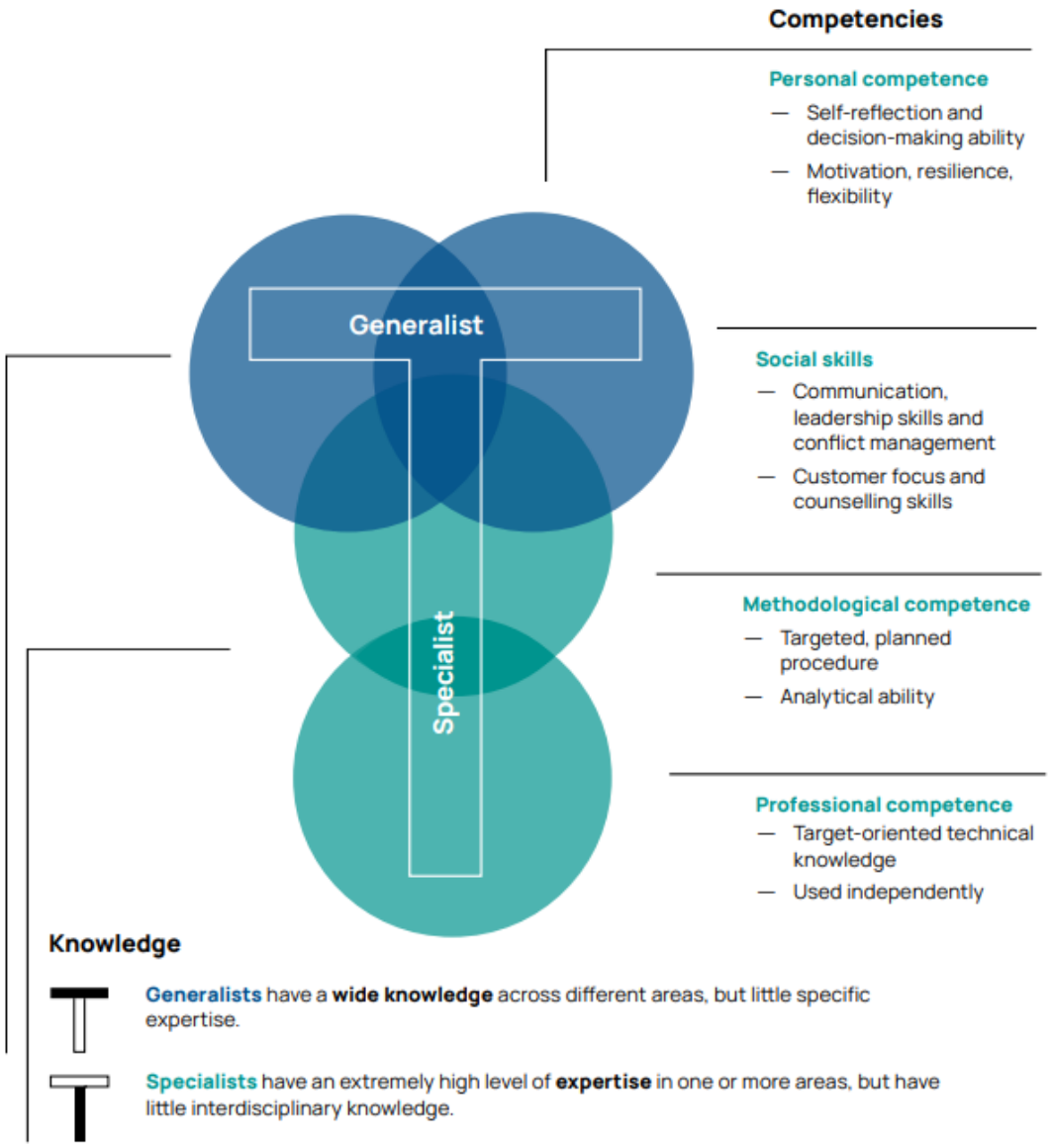


Figure 3-2: T-shape required competency and knowledge model [DAR21, p.111]

A generalist employee is typically recognized as someone with a wide-ranging understanding of various subjects but without the depth of expertise found in specialists. Given their need to work in multiple fields, this position demands strong interpersonal skills.

In contrast, specialists possess in-depth knowledge within specific subject areas through a narrower scope of general awareness. Their expertise is typically formulated during their academic pursuits.

According to KÖNEMANN et al. [KSS+23], future engineers must possess a foundational understanding of each relevant discipline since the challenges within the industry, as frequently said, are increasingly marked by multidisciplinarity. As a result, the significance of the generalist role is steadily growing.

3.1.5 Adapted competency levels defined by BLOOM [BEF+56]

An adapted version, as defined by BLOOM et al. [BEF+56], has been considered to establish the levels of SE competencies, which are characterized by KÖNEMANN et al. [KSS+23, p.3]. BLOOM'S original six levels were redesigned to correspond to four SE competency levels and are presented in Figure 3-3.

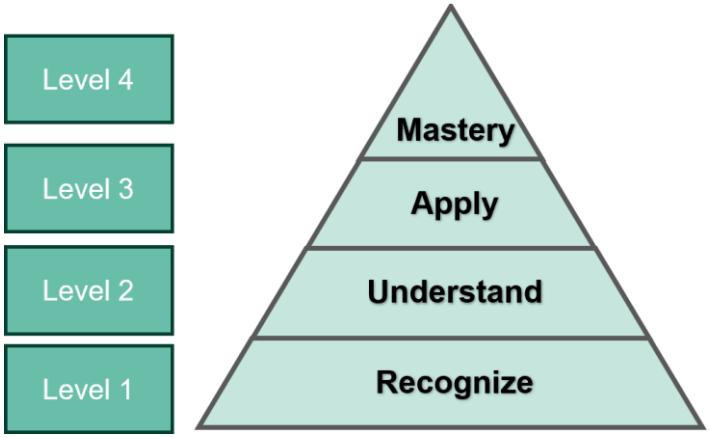


Figure 3-3: Adapted SE competency levels defined by KÖNEMANN et al. [KSS+23]

These four levels represent the qualification goal for SE competencies that are defined below:

- **Recognize**: An SE practitioner possessing the "Recognize" competence level demonstrates the ability to identify and place the relevant content (related to that competency) within its proper context.

- **Understand**: One level above, the individual is capable of understanding and explaining the content related to the competency. This level signifies a deeper grasp of the subject matter and the ability to provide interpretation within the context of competence.
- **Apply**: In the third level, the person is expected to independently apply the knowledge to similar situations, putting their acquired knowledge into practice.
- **Mastery**: At the highest level, the SE practitioner can independently change the scope for different situations while also having the skill to analyze and evaluate the approach effectively.

These are the four levels defined by KÖNEMANN et al. [KSS+23, p.3], enabling different roles to understand the degree of competencies required and the level of depth or detail associated with each competency. This framework provides a comprehensive overview of the extent to which a particular competence needs to be developed. It emphasizes the question of proficiency, specifically "how well" it must be mastered.

We will apply the four competency levels mentioned above in Chapter 4.3.3.3 to determine the appropriate learning formats alongside the SE archetypes. This integration facilitates a more informed LF selection process.

3.1.6 Exploring learning landscapes: types, arrangements, and formats

The learning landscape suggests a comprehensive investigation into various aspects of learning. The title suggests a detailed exploration of the diverse ways learning is categorized, organized, and presented.

3.1.6.1 Learning Formats (LFs)

In addition to formal education, the growing requirement for ongoing professional development and the concept of lifelong learning have become more evident. Suitable learning programs and training models must be developed to meet the needs of many employees in modern companies. This is vital for equipping employees with the skills needed to engage with the development of Advanced Systems [DAR21, p.55].

Learning formats (often used as learning programs) refer to the various ways in which individuals or teams can acquire the necessary skills, knowledge, and certifications to work within the field effectively. These formats can have individual methods or a sequence of methods like seminars, which might include the presentation, videos, audio, a questionnaire at the end of presentations, group discussions, etc.

3.1.6.2 Learning types

Competency development in systems engineering can create a well-rounded and effective approach to skill acquisition and practical application. One can blend various learning methods with competency development in systems engineering. Along with the learning methods, four learning types are explained in VESTER'S work "*Denken, Lernen, Vergessen*" [Fre98] and further analyzed by the MAIKE LOOß in "*Types of Learning*" [Loo01].

These four types include:

- Auditory learning: The learning style strongly prefers information and knowledge acquisition through the sense of hearing. Those with a strong preference for auditory learning often absorb and retain information most efficiently when it is presented in an auditory format, such as through spoken words, storytelling, podcasts, or verbal guidance. This learning style often relies on a strong sense of active listening. The learning planning should be made while keeping auditory learning in mind.
- Visual learning: This style of learning is characterized by a strong preference for processing and retaining information through visual stimuli. Learners may find it more challenging to absorb information conveyed solely through auditory means and often prefer to see information in a concrete, visual form.
- Haptic learning: Haptic learning, also known as tactile learning, centers on touch and physical interaction as the primary way to understand and remember information. People who prefer haptic learning benefit most from hands-on experiences and activities that engage their sense of touch, such as interactive demonstrations. It is essential to add the haptic elements while planning a learning format.
- Learning through the intellect: The initial three forms of learning are connected to the core of sensory perception. Learning through the intellect typically refers to a cognitive or intellectual learning style. It emphasizes the use of reasoning, critical thinking, analysis, and problem-solving as primary methods for acquiring and comprehending information.

3.1.6.3 Learning Arrangements (LA)

A “Learning Arrangement” typically refers to the organized structure or plan for facilitating a lasting learning experience. It contains various components (e.g., the cost-benefit or input-output ratio of further training measures), methods (communication type, learning formats, among others), and strategies used to deliver educational content effectively.

According to PROHASKA, in developing learning arrangements, a key consideration is determining the most appropriate format for the specific needs. The learning arrangement involves webinars, seminars, online courses, or blended learning. Understanding these differences and categorizations is crucial for optimal conceptualization [Pro21, p.28].

For the modern learning arrangement, PROHASKA defined the following requirements that include didactic and methodical concepts of learning arrangements:

- Slow introduction of the learners [p.32].
- Clever format mix [p.32]
- Plan learning times consciously [p.32]
- Adaptive learning [p.33]
- Brain-friendly portions/Learning nuggets [p.33]
- Plan transfer campaigns [p.33]
- Provide orientation [p.34]
- User-generated content [p.35]
- Mobile first [p.35]
- The need for cooperation [p.35]
- Skilful integration of learning formats [p.36]
- Didactic competence [p.36]
- Timing of learning units [p.36]
- Learning support [p.38]
- Set success criteria [p.38]
- The 9 Ws of didactics [p.39]

3.1.7 Qualification archetypes of SE

The archetypes for systems engineering qualification are defined by KÖENEMANN et al. [KSS+23, p.21], as shown in Figure 3-4.

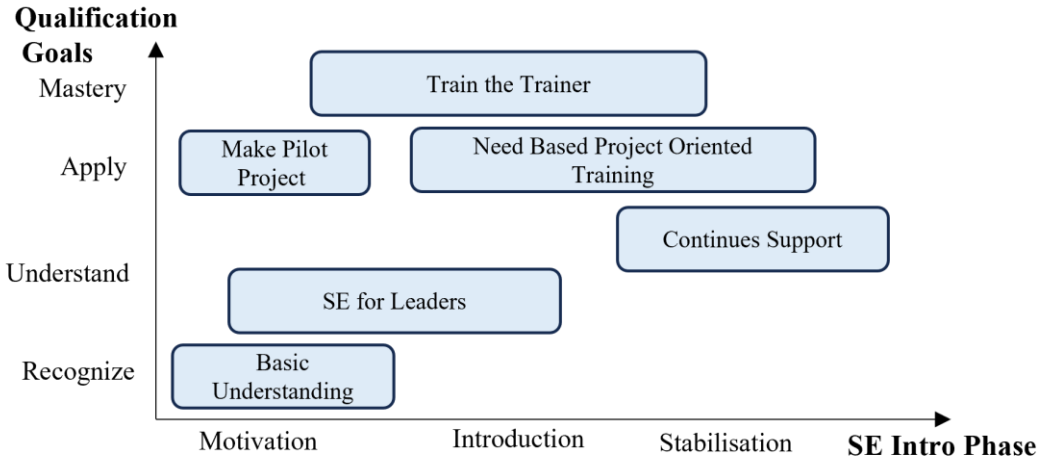


Figure 3-4: Qualification archetypes for Systems Engineering

In Figure 4-1, the x-axis represents the SE introduction phase, categorized as “Motivation,” “Introduction,” and “Stabilisation.” This phase outlines the extent to which SE practices are implemented within the company’s operational context.

- **Phase 1**: The Motivation phase does not have prerequisites, and its objective is to introduce systems engineering by highlighting its advantages when adopted. This phase aims to enhance commitment and trustworthiness to SE and its principles within the team and among individual members.
- **Phase 2**: After the company has acquired knowledge about SE practices, including basic SE processes and methods in group training, the next phase involves introducing these practices to the “Leaders” or “Managers” who play a pivotal role in changing the work environment. These leaders should be made aware of the long-term benefits of SE. In the Introduction phase, hands-on training can be provided to employees or teams, focusing on introducing best SE practices.

- **Phase 3**: The final phase involves the stabilization of SE, where continuous or lifelong learning serves as the foundation for solidifying SE practices in collaboration with management approaches. This phase entails the continuous collection and thorough documentation of information derived from past and present experiences.

In Figure 3-4, on the y-axis, you can observe the learning goals, ranging from the foundational level of "Recognize" to the highest level of "Mastery." A comprehensive explanation of these four competency levels can be found in Chapter 3.1.

KÖENEMANN et al. defined six archetypes as follows [KSS+23, p.21]:

- **Basic Understanding:** The foundational approach for SE involves creating awareness through interdisciplinary exchange, fostering commitment, and establishing a common language space for SE. The emphasis is on understanding the necessity of SE, exploring basic connections, and engaging in collective reflection within a diverse group. This format accommodates stakeholders at different competency levels, and careful participant selection may be beneficial to facilitate meaningful exchanges.

  External trainers typically conduct these training sessions, and suitable qualification formats include blended learning, seminars, and serious gaming concepts that encourage active participation. With no prerequisites, this archetype commonly utilizes external qualification offerings, posing a challenge for participants in transferring learned content due to the absence of company-specific material.

- **SE for Leaders:** The archetype concentrates on decision-makers, which is crucial in steering the adoption of systems engineering. As key enablers, executives must grasp the implications of integrating SE into their organization.

  It is essential to bring potential challenges to light, with serious gaming serving as an approach by simulating development processes to uncover issues. Additionally, blended learning, seminars, and coaching are practical approaches to facilitate this transformative journey.

- **Make Pilot Project:** The hands-on qualification archetype is more toward practical application. It aims to provide participants with a foundation in systems engineering while simultaneously training a team to implement a pilot SE project. The emphasis lies in fostering a team of developers capable of independently determining the benefits of SE. This involves initial topic introduction and ongoing coaching, seamlessly complemented by certification measures like SE-Zert or C-SEP.
- **Need Based Project Oriented Training:** This qualification targets the additional training of specific roles within the company, providing extended support for projects. The training encompasses a range of knowledge levels, from basic to expert, with initial general training for all project participants followed by specialized training for each role. Essential prerequisites for these archetypes include defining company-specific standards, methods, tools, and roles for SE.

  An effective learning arrangement includes a combination of seminars, coaching, video tutorials, and consultation hours, ensuring the active involvement of all team members in the project.

  It is important to get everyone actively involved in the project to familiarize them with the application beforehand, as the qualification can affect the project's duration. It is also crucial to ensure many coaches and trainers for all projects.
- **Continues Support:** The continuous support archetype fosters ongoing learning within the organizational structure. It assumes self-directed learning, emphasizing users proactively seeking knowledge. This involves consistently gathering, documenting, and addressing recurring user queries. For this archetype, a prerequisite is that a significant portion of employees are already qualified.

  Typically, there is no learning support in the form of trainers. Formats like FAQs, video-based learning nuggets, and web-based training are suitable. In cases of specific needs, seminars or other controlled learning formats can still be provided.

- **Train the Trainer:** This qualification approach centers on coaches, trainers, and key stakeholders tasked with introducing SE into the company. Three key aspects need consideration.

  Firstly, it involves imparting the company's specific challenges and working methods to future trainers.

  Secondly, the focus is on ensuring the requisite SE skills and fostering awareness of potential conflicts in systems engineering.

  Thirdly, trainers need to acquire the necessary didactic and moderation skills.

  Certified internal or external trainers can deliver this training. Establishing a trainer community and, if necessary, implementing a train-the-trainer certification within the company is also advisable. A significant challenge lies in identifying suitable individuals for these roles. The integration of external service providers is carefully considered and planned within this archetype.

3.2 Field of actions

The thesis requirements are explained in three primary fields of action, as outlined in the subsequent subchapters. An extensive review of existing literature has been taken to address and satisfy the specific requisites drafted within each field of action. It ensures that the identified gaps are effectively filled to meet the objectives.

3.2.1 Identifying and selecting Learning Formats (LFs)

As mentioned in Chapter 2.2, the first sub-goal of the thesis is to make a comprehensive investigation of different learning formats and their respective features, such as the duration, learning outcomes, communication types, etc., by comparing them through various sources such as [Pro21], [Zeu16], [Ied22-ol], [TG14], and more.

3.2.1.1 Training und Seminare Im digitalen Wandel by PROHASKA

In the book authored by PROHASKA [PRO21], various learning formats are defined in detail, such as seminars, webinars, etc. Multiple parameters are considered while explaining the formats, such as the duration of the format, communication type between the participants and the trainer, and other essential elements that contribute to the overall effectiveness and success of the training experiences.

The focus is not only on offline trainings but also on the e-learning formats, making the literature more useful for conducting in-depth reviews following specific requirements.

The following main learning formats are defined by PROHASKA such as:

- Webinars
- Live Online Events
- Live Online Seminars
- Seminars
- Coaching
- Computer-Based Training
- Web-Based Training
- Game-Based Learning
- Blended Learning

The training programs are defined in general without considering the aspects of SE that are missing in the literature. The lack of consideration for SE aspects in training programs

limits their effectiveness. It leaves a gap in the literature that needs to be addressed in order to fully utilize the training programs for systems engineering.

3.2.1.2 Betriebliche Seminare und Trainings entwickeln by KAUFFELD

KAUFFELD [Kau10], in his book "Nachhaltige Weiterbildung - Betriebliche Seminare und Trainings entwickeln, Erfolge messen, Transfer sichern" describes a wide range of learning methods employed in various industries, and these methods can also be applied to future learning programs. Additionally, it provides a brief introduction to LFs and the methods that can be used for micro planning. Furthermore, KAUFFELD offers insights into various training tools, including "act4teams" [Kau10, p.92], as well as other valuable resources and strategies for training program development.

KAUFFELD defines the following primary learning formats:

- Face-to-Face Online Training
- Web Conferences
- Seminars
- Training on the job
- Coaching
- Mentoring
- Computer-Based Training
- Web-Based Training
- Game-Based Learning
- Blended Learning
- Training Off the Job
- Training Near the Job
- Simulations, among others

Formal formats, such as seminars and coaching, were well defined, and the informal learning formats, like peer reviews, learning in tandem, and learning via network, had their place. However, none of these learning formats considered the characteristics of systems engineering in their programs. This distinction revealed a critical gap in the development of professionals within these contexts, particularly for individuals seeking a broad understanding of systems engineering.

3.2.1.3 Building an Information Security Awareness Program by THOMAS

In his book, THOMAS explores a range of training methods and goes through their advantages and disadvantages. In Chapter 9 of the book, "Types of Training," various training techniques were explained. Training types like Web-Based and Computer Based are very well described with informal training like lunch and learn sessions and home-made video campaigns.

THOMAS defined the following primary learning formats:

- Instructor Lead Training
- Computer-Based Training
- Web-Based Training
- Video Training, among other Informal Training

One of the areas for improvement is that the training types were limited and more focused on information security rather than fulfilling the requirements of the thesis, which should have prioritized training programs based on systems engineering principles.

3.2.1.4 Corporate Training for Effective Performance by MULDER

In their book, MULDER et al. [MNB95] focus on various aspects of training. They discuss the changing environments of training, the utilization of new training devices, and, most importantly, they assess the effectiveness of training by synthesizing information from various sources. This literature covers a wide range of training methods, including training via simulated devices, mentoring, coaching, and other helpful resources to improve learning and development.

MULDER defines the following primary learning formats:

- Seminar
- Training via Simulated Games
- Behaviour Modelling Training
- Coaching
- Mentoring
- Leadership Training
- On the Job Learning

The strategies outlined within this literature offer valuable insights that can be applied to the planning and evaluation of training programs. However, a notable limitation lies in the inadequate coverage of learning methods within the literature. Another drawback is the need for a transparent categorization system for different types of learning and communication. Furthermore, there is no reference to systems engineering within this context, which could provide a holistic perspective on training effectiveness and optimization.

3.2.1.5 Handbook of Human Resources Management by ZEUCH

ZEUCH combines a variety of general and detailed articles, it offers the reader a well-rounded perspective that covers all aspects, giving a comprehensive understanding of the topics. The book is organized into several sections, providing information about various learning programs and discussing the topic of change management within companies with other valuable insights [Zeu16].

ZEUCH defines the following main formats:

- Seminar
- Online Seminar
- Virtual Conferences
- Coaching
- Mentorship
- Computer-Based Training
- Web-Based Training
- Game-Based Learning
- Mobile Learning
- Blended Learning
- Leadership

Additionally, it introduces the concept of “Web 2.0” [p.310] learning, encompassing informal learning methods. Moreover, the book offers a comprehensive definition of “New Learning” by integrating various learning techniques, as highlighted by ZEUCH [Zeu16, p.300]. One significant distinction between the thesis requirements and the existing literature lies in neglecting systems engineering qualifications, leaving a prominent gap in understanding training programs and general learning processes.

3.2.1.6 Further literature

In pursuing information regarding various learning programs, it is essential to recognize valuable resources. ABDULSADA et al. [AD23] provide an insightful analysis of webinars, offering valuable insights by looking into the speech acts during webinars. A handful of learning types were explained by MARIA [Lin22-ol], which explores various learning methods and clarifies their suitability under different events while thoroughly examining their pros and cons. This comprehensive examination gives individuals the knowledge and insights to navigate the training landscape effectively.

LONGMUß, in their work [LH17], presents the concept of agile learning in the workplace, where learning occurs in iterative "Sprints." This approach follows agile development principles with adaptations tailored to learning environments. These adaptations include incorporating a digital learning environment within the organization, explicitly defining weekly learning objectives, and integrating coaches and instructors into the agile learning process. This approach aims to enhance the efficiency and effectiveness of workplace learning, enabling continuous improvement and adaptation to meet the evolving needs of the modern workforce.

Numerous valuable academic sources offer comprehensive insights into learning methods. For instance, MOICA et al. [MGV+16] shed light on the integration of blended learning concepts into employee training programs, elucidating the evolving landscape of professional development. These works serve as vital resources for understanding the dynamic approaches to enhancing employee qualifications. MARIA et al. [SFS19] compare face-to-face conferencing and virtual conferences. SCHRADER [Sch23] focuses on the usefulness of game-based learning in the learning environment.

For the requirements, Other works of literature were also found helpful in identifying and explaining the characteristics of the learning formats, such as [GKK+16], [Lib20-ol], [GE17], [MJM+23], among other resources.

3.2.2 Identifying the characteristics for selecting LFs in SE

After determining the learning formats, the following step involves identifying the specific characteristics pertaining to systems engineering that can be applied and incorporating them into each refined learning method. To identify these characteristics, an extensive review of relevant literature was conducted, as outlined in the subchapters of this Chapter. This comprehensive literature survey served as a critical foundation for aligning the learning methods for systems engineers.

3.2.2.1 Principles for the effective application of SE

MUNDT et al. [MWA+23] demonstrate the fundamental principles governing the proficient implementation of Systems SE within industrial settings. They make a systematic literature review and identify the 12 SE principles. These 12 principles can be leveraged to define the characteristics that will be further used in learning methods.

The 12 SE principles include:

1) Transdisciplinarity
2) Holisms
3) Stakeholder-Centricity
4) Reuse and Standardization
5) Risk-driven and Evidence-based Decision-making
6) Early Verification and Validation
7) Interface Management
8) Documentation
9) Effectiveness over Efficiency
10) Iteration and Adaptability
11) Complexity to Manage Complexity
12) Top-Down and Up-Front Development

SE principles can serve as a foundational framework for establishing characteristics evaluation. However, conducting a comprehensive and rigorous assessment is crucial,

reaching a point where it becomes clear whether all or a subset of these principles are applicable. An in-depth review, coupled with expert evaluations, is necessary to meet the requisite thoroughness.

The literature does not encounter the topic of competency and learning formats thus, a comprehensive exploration of these requirements is required.

3.2.2.2 INCOSE SE handbook

The INCOSE handbook [INC23] is a valuable resource that may provide relevant information on SE-related characteristics, as it addresses the definition of role-specific values for systems engineers. A thorough review is necessary before reaching a point where specific characteristics can be derived. It is crucial to explore this further to establish a well-informed conclusion. Limited information is available in the handbook regarding SE competencies, and the relation between the SE competencies and the learning formats is not considered.

3.2.2.3 INCOSE SE competency framework

INCOSE defined an SE competency framework [BGD+18], where all 36 competencies were explained in detail as it is shown in Table 3.1. The framework offers invaluable direction to both recipients and SE practitioners in understanding essential attributes, namely knowledge, skills, competencies, and behaviors, needed to enhance the efficacy of SE within the specified domain to which the competency model is suitable.

Learning programs are not defined for the competencies, and there is also a missing link between the SE competencies and SE learning programs.

INCOSE defined the competencies into five significant categories, i.e.,

- Core Competencies
- Professional Competency
- Technical Competencies
- Management Competencies
- Integrating Competencies

CORE COMPETENCIES	PROFESSIONAL COMPETENCIES	MANAGEMENT COMPETENCIES	TECHNICAL COMPETENCIES	INTEGRATING COMPETENCIES
Systems Thinking	Communications	Planning	Requirements Definition	Project Management
Lifecycles	Ethics and Professionalism	Monitoring and Control	System Architecting	Finance
Capability Engineering	Technical Leadership	Decision Management	Design for…	Logistics
General Engineering	Negotiation	Concurrent Engineering	Integration	Quality
Critical Thinking	Team Dynamics	Business and Enterprise Integration	Interfaces	-
Systems Modeling and Analysis	Facilitation	Acquisition and Supply	Verification	-
-	Emotional Intelligence	Information Management	Validation	-
-	Coaching and Mentoring	Configuration Management	Transition	-
-	-	Risk and Opportunity Management	Operation and Support	-

Table 3.1: SE competencies defined by INCOSE

3.2.2.4 Identification of […] SE competencies for industry by KÖNEMANN et al.

KÖNEMANN et al. [KWA+22] introduce a notion for recognizing SE skills tailored to various stakeholders within the organization. The competencies established by the International Council on Systems Engineering (INCOSE) have undergone a comprehensive review and redesign aimed at enhancing their clarity and applicability. The revised iteration comprises a total of 16 competencies, which have been thoughtfully restructured into distinct groups. Notably, an unexplored competency, namely "Agile Development," has been introduced to enhance the framework further. Proficiency in agile competencies is essential for the successful management and execution of projects and product development within an agile environment.

We will use the revised competencies defined by KÖNEMANN et al. in the documentation to examine the relationship between SE competencies and learning formats. The research offers limited information about the learning programs, which may be taken through external sources or the deduction of insights and knowledge.

KÖNEMANN et al. defined the adapted framework of INCOSE competencies categories and grouped them as follows:

- Core Competencies
- Social / Personal Competencies
- Management Competencies
- Technical Competencies

These 4 categories consist of the 16 competencies as shown in Table 3.2

CORE COMPETENCIES	SOCIAL / PERSONAL COMPETENCIES	MANAGEMENT COMPETENCIES	TECHNICAL COMPETENCIES
Systems Thinking	Communications	Project Management	Requirements Definition
Lifecycle Consideration	Leadership	Decision Management	System Architecting
Customer / Value-orientation	Self-Organization	Information Management	Integration,Verification, Validation
Systems Modeling and Analysis		Configuration Management	Operation and Support
			Agile Methods

Table 3.2: Adapted INCOSE competency framework

3.2.3 Methods to develop Learning Arrangements (LAs)

Structuring learning formats involves designing organized and tailored learning arrangements that align with specific learning goals. The aim is to optimize learning experiences, fostering skill development and knowledge acquisition for systems engineers within well-defined learning programs.

In the process of designing courses, it is crucial to take into account the learning typologies outlined by VESTER [Fre98] and later adapted by MAIKE LOOß [Loo01, p.1]. These typologies shed light on the various ways in which learners acquire knowledge and skills. In this regard, it is noteworthy to incorporate four distinct learning styles, each of which plays a significant role in the learning process. These styles serve as valuable insights into understanding learner's engagement with educational material and can significantly advise the course design process.

3.2.3.1 Literature based on the LFs

The literature described in Chapter 3.2.1 serves as a valuable resource for outlining the micro-planning aspects of learning formats. Within this literature, various methods are proposed, each of which may be applied in the process of formulating learning program planning. It is noteworthy that certain practices offer distinct advantages over others. Therefore, it is imperative to conduct comprehensive research prior to finalizing the most suitable methods to fulfill the requirement.

3.2.3.2 Leitfaden zur Systems Engineering Qualifizierung by KÖNEMANN et al. [KSS+23]

KÖNEMANN et al. [KSS+23, p.21] define the archetypes of Software SE qualification by taking into account the maturity of the companies introducing SE into their environment and the objectives of the qualification for these companies. The literature clarifies six archetypes, accompanied by recommendations on learning programs that can be utilized to meet these qualifications. The defined approach is employed to specify the learning format for each of the identified archetypes. Extensive research in this direction necessitates expert guidance.

The archetypes clarified in Chapter 3.1.7 are integral to the research conducted by KÖNEMANN et al. These archetypes are later utilized to suggest suitable learning formats.

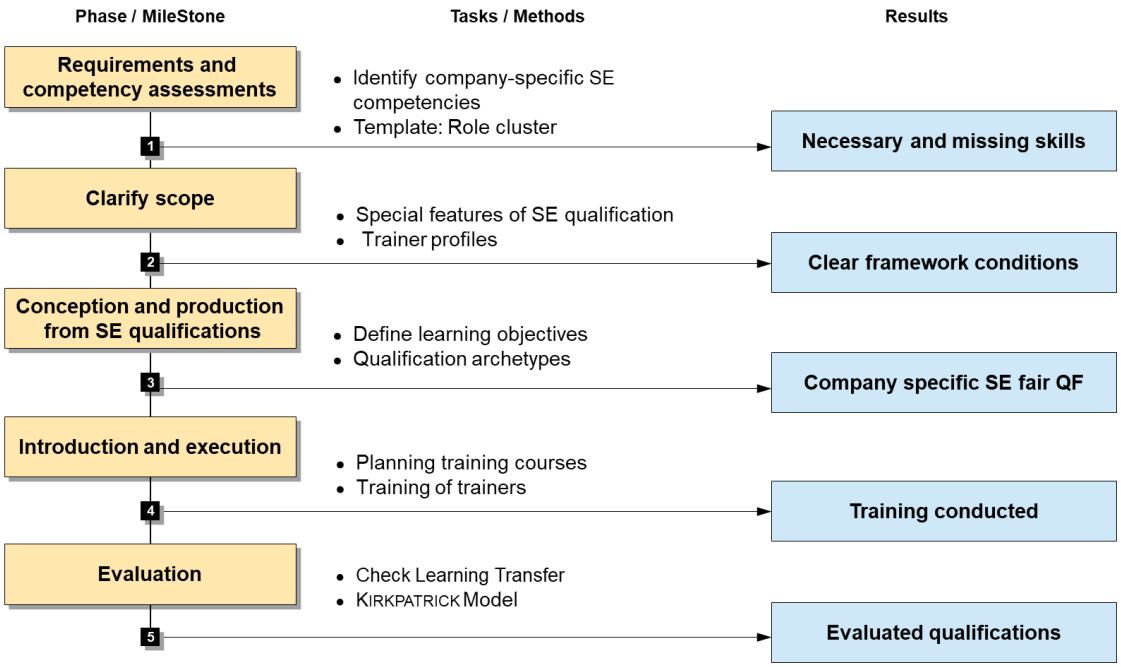


Figure 3-5: Process model to structure and implement qualification in SE [KSS+23, p.2]

The process model (Figure 3-5) is explained in detailed by the KÖNEMANN et al. [KSS+23, p.2], where the process commences with the requirements specified under "Tasks/Methods". For each task, a "Milestone/Phase" is defined, attainable upon obtaining the relevant information from the tasks or methods outlined as requirements. "Results" are achieved at the conclusion of each milestone (or phase). These steps serve as a foundation to which additional tasks and methods will be added (tasks that this thesis aims to facilitate). The newly acquired methods and tasks will contribute to furthering the planning framework for implementing SE qualifications.

The “Phases/Milestones” of the process mentioned in Figure 3-5 are explained below:

1) **Requirement and Competency Assessment**: For the first milestone, SE competencies are defined, as it is crucial for the company to be aware of the competencies that hold significance for them or those that are already in place. The definition of competency is explained by presenting an overview of qualification goals based on BLOOMS taxonomy [BEF+56] to provide a comprehensive understanding of the topic. Additionally, SE competencies are defined by offering insights into the T-shaped competency model. After establishing competencies, the subsequent step involves determining the roles of individuals in the industry along with their assigned tasks. Subsequently, an analysis of tasks helps identify the competencies necessary or beneficial for task fulfillment, leading to the role and stakeholder-specific competencies. Once competencies are outlined for each role, the final step involves evaluating these competencies through various methods, such as assessment centers and interviews. The results of this milestone highlight the necessary and missing skills.

2) **Clarify Scope**: The second milestone focuses on aspects of qualification planning based on DIN1031-1 [PAS 1032-1]. The connections between competence and qualification are defined by distinguishing between training and further education. In the subsequent steps, challenges of systems engineering qualification and general framework conditions are highlighted, such as interdisciplinary aspects, complexity, mindset, and change, among others. The following step explains the trainer and coach competency profile by detailing the skills of these profiles, including professional skills, methodological skills, experiences, social skills, etc.

3) **Conception and Production from SE Qualifications**: The third milestone encompasses the establishment of learning objectives, the selection of learning formats, and the structuring of modules and learning units. The objective is to optimize the effectiveness of learning transfer, which serves as the foundation for successful qualification. Detailed explanations are provided for various learning formats, including seminars, coaching, serious gaming, blended learning, web-based training, and mentoring. The subsequent step involves defining qualification archetypes for systems engineering. Each archetype typically employs specific learning formats, which are then combined to create comprehensive learning arrangements. It gives the company-specific SE LFs.

4) **Introduction and Execution**: Based on the steps carried out in the first three milestones, the fourth milestone involves the introduction and conduct of training courses. When incorporating learning management systems (LMS) into systems engineering qualification, it is crucial to strategically plan the implementation and introduction of this tool. It is also important to clarify how the registration for the training course is going to work, and the training days should be planned in advance, considering the availability of the trainers during times of high demand. This milestone results in the successful conduction of training.

5) **Evaluation**: After the completion of the training, the final phase involves assessing the trainer's performance to identify areas for improvement or understand its effectiveness for the trainee. The evaluation of qualification measures and training success often employs the well-known four levels of the KIRKPATRICK Model [Kir94]. These levels, arranged from bottom to top, consist of "Reaction," "Learning," "Behaviour," and "Results." Paying special attention to the "Behaviour" and "Results" levels is crucial for the successful implementation of systems engineering qualification.

3.3 Evaluation of state of art

Table 3.3 presents the list of the most important literature sources that have been reviewed for the defined requirements and fields of actions.

Evaluation of Requirements Evaluation scale: ○ = Not fulfilled ◑ = Partially fulfilled ● = Fulfilled	Identification of Learning Formats (LFs) and their characteristics		Identifying the criteria for selecting LFs in Systems Engineering (SE)		Methods to develop learning arrangement		
	Overview of the LFs	Characteristics of LFs	Criteria for selecting LF for SE	Link b\w the SE competencies and the LF	Planning for learning arrangement	Planning using Learning Methods	Define the archetypes of SE qualifications
	R1	R2	R3	R4	R5	R6	R7
Training Und Seminare Im Digitalen Wandel - Prohaska, Pro21	●	◑	○	○	◑	◑	○
Nachhaltige Weiterbildung - Kauffeld, Kau10	●	◑	○	○	◑	◑	○
Types of Training - Valerie, TG14	●	◑	○	○	◑	◑	○
Linking Corporate Training and Effective Performance - Mulder et al., MNW+95	●	◑	○	○	◑	◑	○
Handbook of Human Resources Management - Zeuch, Zeu16	●	◑	○	○	◑	◑	○
Speech Act Analysis of Educational Webinars - Abdulsada et al., AH22	◑	◑	○	○	○	○	○
Learning Format Types - Lin22-ol	●	◑	○	○	○	○	○
Agile Learning for Vocationally Trained Expert - Longmuß et al., LH17	◑	◑	○	○	○	○	○
Mentoring - Graf et al., GE17	◑	◑	○	○	○	◑	○
The Integration of the Blended Learning Concept into Employee Training - Moica et al., MGV+19	●	◑	○	○	○	○	○
Virtual and Face-To-Face Academic Conferences - Maria et al. SFS19	●	◑	○	○	○	○	○
Identification of Stakeholder-specific SE Competencies for Industries - Könemann et al., KWA+22	○	○	◑	●	○	○	○
Systems Engineering in Context - Adams et al., ABL+19	◑	○	○	○	○	○	○
Leitfaden zur SE Qualifizierung - Könemann et. al., KSS+23	◑	◑	●	●	◑	◑	●
INCOSE Systems Engineering Competency Framework - Beasley et al., BGD+18	○	○	◑	◑	○	○	○

Table 3.3: Mapping literature and state-of-the-art (requirement).

The metric employed for aligning the requirements with the existing literature is structured around three distinct levels: namely, not fulfilled, partially fulfilled, and fully fulfilled. As an illustrative instance, PROHASKA [PRO21] book entirely satisfies the "Overview of learning formats," denoted as R1, including a part of the first field of action, which is "Identification of learning methods and their characteristics."

As depicted in Table 3.3, Requirements R1 and R2 are supported by multiple resources that provide partial information regarding identifying learning formats. However, there is a need to group and compare different sources to determine the best formats. In the case of Requirements R3, R4, and R7, limited information is available. The works of KÖNEMANN et al. [KSS+23] and BEASLEY et al. [BGD+18] lay a solid foundation for establishing a link between SE competencies and learning formats, with clear information on SE qualification archetypes. The results of MUNDT et al. [MWA+23] are crucial in identifying SE qualification and learning characteristics. As for Requirement R6, the necessary elements for planning learning formats can be found in various literature sources.

4 Solution design for the field of actions

Upon establishing well-defined requirements and a comprehensive review of the relevant literature, the subsequent chapter involves formulating a solution design. The chapter is divided into three main subchapters, each of which is grounded in the three distinct fields of action outlined in Chapter 3.2. Each subchapter thoroughly outlines the specific requirements relevant to its corresponding field of action. This structured approach ensures a systematic and thorough exploration of the literature for the solution design process.

4.1 Identifying and selecting LFs

The initial course of action entails comprehensively identifying most of the learning formats within the existing literature, which may or may not be directly associated with systems engineering but have been delineated in diverse scholarly sources. Thereafter, upon identifying these learning programs, the subsequent step involves formal representation through a clear definition. This consists of defining different characteristics of the learning formats.

4.1.1 Comparative analysis and elaboration of the LFs

The initial step involves the identification of learning formats as recommended in the existing literature. A majority of the literature sources outline these formats within Chapter 3.2.1. These formats exhibit slight variations in their definitions across different references; however, a common conceptual understanding is derived from these sources.

In Table 4.1, at the top (header) of the table, various literature sources used to define the learning formats are displayed, along with the column labeled “Specific References” (presented in Appendix A1), which contains research related to specific learning formats. The last column of the table summarizes the final nomenclature of the learning formats used in this documentation, named as “Summary.”

Reference - 1 (Prohaska, Pro21)	*Reference - 2 (Kauffeld Kau10)*	*alerie,*	*Summary*
Live Online Seminar/ Live Online Training	-		**Online Seminar**
Blended Learning	Blended Learning		**Blended Learning**
-	-		**Agile Learning**
Coaching	Coaching		**Coaching**
Computer Based Training	Computer Based Training	ining	**Computer Based Training**
Webinar / Live Online Event / Video Conferences	Face to Face Online Trainir		**Webinar**
Games Based Learning/Gamification	Games Based Learning/Gamification		**Games Based Learning**
-	Mentoring		**Mentoring**
Seminar/ Classic Seminar	Seminar	ng /	**Seminar**
Web Based Training	Web Based Training		**Web Based Training**
-	Web Conferences		**Conferences**

Table 4.1: Comparing identified learning formats from various sources

We observed similarities in the planning process for certain learning formats despite using different names. For instance, in the case of "Game-Based Learning," various terms were employed, such as "Training via Simulated Games," "Gamification," and "Serious Gaming." However, we ultimately opted for an umbrella term, "Game-Based Learning," to encompass these diverse yet related approaches.

The learning format name "Online Seminar" is not formally defined within this documentation, primarily due to limited available knowledge and its relatively uncommon structure in the context of the subject matter.

"Agile Learning" is mainly viewed as a practice that is integrated into the learning process rather than being a distinct LF. As explained by LONGMUß et al. [LH17, p.2], learning

can take the form of "Sprints," with specific learning tasks designated for each sprint. In these sprints, dedicated team members oversee the progress and provide learning resources within the organization. This approach also involves the introduction of a learning culture in the organization. Trainers can incorporate agile learning seamlessly into blended learning, web-based, or computer-based training formats. Learning in sprints aligns with the principles of agility in education.

The complete table, comparing learning formats from various sources, is included in "Appendix A1." It illustrates the comparisons of different names used by multiple authors and lists the finalized methods.

In the discussion of defined learning formats, it is essential to consider both their advantages and disadvantages. While some formats share common disadvantages, these drawbacks are often mentioned without detailed explanations, and instead, only the names of the advantages or disadvantages are provided in the explanations below.

1) Seminars/Instructors Lead Training

Seminars or terms as classic seminar, takes place in the room. In addition to linguistic and rhetorical means, one can use individual and mostly dynamic body language and benefit from the resulting effect. An interaction takes place and is explicitly desired. The trainer defined the content, the methods, and the time organization in coordination with the client [Pro21].

A seminar is a commonly used method to train employees as part of an offsite method. It usually takes place away from the workplace and is led by one or more experts. A large number of participants can be trained at the same time [Kau10]. It includes the use of slideshows, videos, storytelling, and lectures (primary delivery method) that are custom-built for the target audience [TG14].

The main advantage of the seminars includes:

- **Direct Feedback**: In a seminar, participants can interact with the trainer to discuss the topics and clear their doubts during the session.
- **Standardized Content:** The learning material presented by the instructor is generally standardized, measured, and tested. Such that participants get up-to-date knowledge**.**
- **High Interaction:** The interaction between the participants is high if group discussions or roleplay are added as a learning arrangement for the training. Participants get a different perspective on the same topic.

The main disadvantage of the seminar includes the following:

- **Limited Accessibility**: The seminar is unsuitable for online learners since the program is face-to-face in-presence training.

- **Lack of Self-Paced Learning**: Seminar often follows a predetermined schedule with fixed topics and timelines. This structured approach may not be suitable for self-paced learners who prefer to study and absorb content at their own pace.
- **Travel and Expenses**: Attendees often need to incur travel expenses, including transportation, accommodation, etc., to attend face-to-face seminars. This can be costly and may deter some from participating.

2) Webinars or Live Online Events

The webinar will take place at a specific time. The interaction between lecturers and participants takes place via chat; in individual cases, however, individual participants also receive audio access via moderator rights. A characteristic of webinars is that an unlimited number of people can participate, and the communication between the participants and the trainer(s) is synchronous. The duration is usually 30 to 90 minutes [Pro21].

Webinars encompass a range of online events, including live broadcasts, pre-recorded sessions, and scheduled seminars designed to explore various educational, business, scientific, or other topics. Webinars typically attract a significant audience. Webinars often prioritize speech acts as they allow clear and effective communication of meanings and emotions [AD23].

Listing the primary advantages of webinars encompasses the following key aspects:

- **Direct Feedback**: In a webinar, participants can engage with the trainer to discuss topics and resolve their doubts during the session. Webinars provide participants with the capability to unmute themselves and actively participate in the discussion.
- **Global Reach**: Webinars can reach a global audience, transcending geographical boundaries and language barriers.
- **Standardized Content**: It aligns with the same definition described in the seminar's advantages.

Listing the primary disadvantages of webinars encompasses the following key aspects:

- **Limited Instructors**: Finding a dedicated trainer with the appropriate qualifications that match company needs can often be a challenging task.
- **Low Interaction**: The level of interaction among participants is generally low and often depends on the activities carried out during the program.
- **Lack of Self-Paced Learning**: It aligns with the same definition described in the seminar's disadvantages.

3) Coaching

This requires attentive observation of the learner's approach. The expert assists through cues if the learner gets stuck working on a task alone (for example, the expert refers the learner to documents and materials where relevant information can be found). However, the support gradually faded as the learner's competence grew. Feedback is also part of the coaching. This gives the learner an external perspective on their actions, thus providing learning cues. The aim of coaching is for the learner to align their approach as closely as possible to the expert model [Kau10].

Coaching can be exercised on an individual, team, or organizational level. Participants discover new cultural choices. Powerful coaching questions can be practiced like "Open-Mindedness," diversity, and more [Zeu16].

The main advantages of coaching include the following:

- **Accountability**: Coaches hold individuals accountable for their actions and commitments. This accountability helps individuals stay focused, motivated, and on track toward their goals.
- **Personalize Guidance**: The learning format provides one-on-one support and tailored guidance to the individual's needs, goals, and challenges.
- **Self-Discovery**: The LF encourages self-reflection and self-discovery. Individuals gain a deeper understanding of their strengths, weaknesses, values, and beliefs, which can lead to personal growth and self-improvement.

The primary drawbacks associated with coaching are as follows:

- **Gradual Results**: Coaching is a process that takes time and effort. It may not provide immediate solutions to complex problems, and individuals may need to be patient and persistent in their efforts.
- **Time Intensive**: Coaching often requires a significant time commitment, both for the coach and the coaches, which may not be feasible for everyone.
- **Limited Instructors**: It aligns with the same definition as described in the advantages of the seminar.

4) Mentoring

According to KAUFFELD [Kau10], mentoring can be defined as individuals acquiring knowledge by directly engaging with work-related tasks. This learning process occurs under the mentorship of a skilled and experienced colleague, who serves as a role model for effectively completing these tasks. The less experienced employee, or novice, benefits from immediate feedback provided by the mentor, allowing for continuous improvement and skill development.

Mentor-training sessions were designed and conducted to provide managers with the opportunity to learn how to coach each other. [MNB95]

A successful mentoring program should encompass clear objectives, well-defined processes, established procedures, defined roles, and a system of accountability, including performance metrics. The program's goals can be customized to align with the company's requirements and the unique needs of individuals [Zeu16].

The advantages of Mentoring are:

- **Successor Training**: Mentoring aids in succession planning by identifying and preparing future leaders within the organization.
- **Personalize Content**: The LF offers personalized content delivery, adapting challenges and resources to individual learners for a more engaging and effective learning experience.
- **Self-Discovery**: It aligns with the same definition as described in the advantages of coaching.

The possible disadvantages of mentoring are as follows:

- **Time Intensive**: It aligns with the same definition as described in the disadvantages of coaching.
- **Gradual Results:** It aligns with the same definition as described in the disadvantages of coaching.
- **Limited Instructors/Mentors**: It aligns with the definition described in the disadvantages of coaching.

5) Web Based Training (WBT)

It is a computer-aided, multimedia training taken via the internet. Participants can call up the content at any time and control the learning at their own pace and according to their available time [Pro21].

Access to the learning software is via the internet. Content can be updated swiftly, and instructors can directly "manage" the course by making changes or unlocking specific modules, allowing for individually tailored learning. Participants can interact with each other and instructors through chat or email [TG14]. The communication is asynchronous.

The following points elaborate on several benefits of WBT:

- **Allows Tracking and Assessment**: WBT often includes tracking features that allow administrators to monitor learner's progress and performance, making it easier to assess the effectiveness of training programs.
- **Self-Paced Learning**: Learners can pause and return to ILT courses as needed and learn at their own pace, promoting flexibility and autonomy in their learning journey.
- **Global Reach**: It aligns with the same definition as described in the advantages of webinars.

The following points elaborate on several disadvantages of WBT, highlighting its limitations and challenges in a learning context.

- **Low Engagement**: Not all WBT programs are designed to be engaging, and some may lack interactive or multimedia elements, potentially leading to reduced learner engagement.
- **Very Low Interaction**: The interaction between the instructors and participants is shallow in this learning format. Some asynchronous methods can be used in communication.
- **Limited Instructor guidance**: WBT may lack an instructor's immediate guidance and support, making it challenging for learners who require personalized assistance or clarification on complex topics.

6) Computer Based Training (CBT)

CBT is a computer-assisted multimedia learning program that comprises structured learning materials. Users can typically access its content independently of the Internet, as the software is installed on the computer, enabling autonomous learning even without an active network connection and providing a flexible and self-paced learning experience [Kau10], [Pro21].

The main advantages of CBT include:

- **Allows Tracking and Assessment**: It aligns with the same definition as described in the advantages of web-based training.
- **Self-Paced Learning**: It aligns with the same definition as described in the advantages of web-based training.
- **Global Reach**: It aligns with the same definition as described in the advantages of webinars.

The main disadvantages of the CBT include:

- **Low Engagement**: It aligns with the same definition as described in the disadvantages of web-based training.
- **Very Low Interaction**: It aligns with the same definition as described in the disadvantages of web-based training.
- **Technical Issues**: Learning disruptions can result from technical issues, including software errors, problems with internet connectivity, or hardware malfunctions.

7) Game-Based Learning

It involves integrating game elements and concepts, such as status, levels, and bonuses, into diverse non-game settings. In the realm of training and continuing education, the primary objective is to offer an engaging and interactive approach to accessing content. By doing so, the learner should not only gain knowledge but also feel entertained throughout the learning process, making the educational experience both enjoyable and informative [Sch23].

In the documentation, we consider game-based learning as an umbrella term encompassing various approaches, such as gamification, serious learning, and learning through games. This inclusive perspective reflects the diverse ways in which games and interactive elements can be utilized in the domain of education and training.
The main advantages of game-based learning encompass:

- **Measurable Outcomes**: The format allows for the measurement of specific learning outcomes and performance improvements, enabling organizations to assess the effectiveness of their training programs.
- **Personalize Content**: The game-based learning offers personalized content delivery. A topic-specific or qualification-specific game can be developed, providing participants with an interactive platform to play and, in the process, learn valuable knowledge and skills.
- **High Interaction**: The level of interaction and discussions among players is notably high, especially in multiplayer games. In such games, players engage in dynamic conversations and strategize together.

The disadvantages of game-based learning encompass several factors that should be considered, such as:

- **Limited Knowledge Transfer**: Serious games may prioritize engagement over in-depth content coverage. While they are effective for experiential learning, they may not provide the same level of depth as traditional educational materials.
- **High Initial Development Cost**: Creating high-quality (serious) games can be expensive and time-consuming. Developing engaging and effective game-based content requires highly skilled teams.
- **Technical Requirements**: Game-based learning may require specific hardware or software, such as gaming consoles or powerful computers. Access to these technologies may be limited for some learners.

8) Conferences

Conferences serve as a valuable social platform for individuals to showcase their research, gain insights into the work of their peers, and engage in formal and informal interactions. These events are structured, time-bound gatherings of professionals, well organized and attended in person. They contain a diverse range of presenters and participants who engage with one another in real-time or through asynchronous means, fostering an environment conducive to the exchange of knowledge and ideas [SFS19].

Attending such events can also help individuals stay updated with the latest trends and developments in their study area and gain exposure to new research topics and methodologies.

The main advantages of conferences include:

- **Exposure To New Ideas**: Conferences often showcase innovative ideas, projects, and technologies. Exposure to new concepts can inspire creativity and innovation in attendee's work or research.
- **Standardized Content**: It aligns with the same definition described in the seminar's advantages.

The main disadvantage of the conferences includes:

- **Medium Interaction**: Conferences exhibit a relatively high engagement among the participants. However, the interaction between the presenters and participants remains notably limited.
- **Time-Consuming**: Conferences often span several days, requiring attendees to dedicate a significant amount of time away from their regular work or responsibilities.
- **Travel and Expenses**: It aligns with the same definition as described in the disadvantages of the seminar.

9) Blended Learning

Blended learning is a versatile approach that integrates synchronous and asynchronous learning formats to create a holistic training module. It combines in-person training elements like seminars and coaching with online training formats like web-based and computer-based training. Other methods can be incorporated into blended learning, such as asynchronous discussion forums, guided lab activities, learning management systems, documentation, etc.

The aim is to maximize the benefits of e-learning while addressing its limitations, such as the lack of face-to-face interaction, by combining synchronous and asynchronous training methods. It aims to provide learners with a flexible, well-rounded educational experience promoting knowledge retention and skill development.

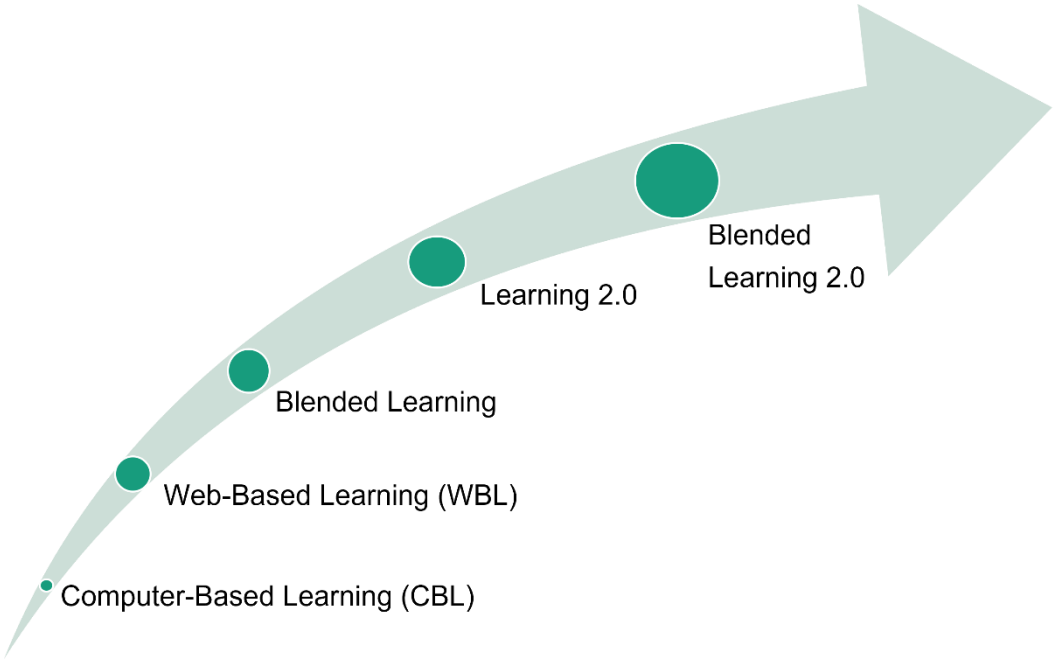


Figure 4-1 Transformation of digital learning support over time [Zeu16, p.299]

Figure 4-1 explains the evolution of learning. Blended Learning 2.0 explained as programs necessitate learners to possess well-developed self-organization and self-directed learning abilities. Additionally, managers need to support their employees, while instructors play a crucial role in guiding the learning process [Zeu16, p.299].

Blended learning offers numerous advantages, and a few of them are outlined below:

- **Self-Paced Learning and High Interaction**: As previously mentioned, this program combines elements of both offline and online learning programs, making it suitable for both self-paced learners and those who prefer interacting with fellow trainees.
- **Standardized Content**: It aligns with the same definition described in the seminar's advantages.

Blended learning comes with its own set of disadvantages, which are elaborated below:

- **Course Planning Hurdles**: There is a need to balance online and in-person components effectively, ensuring seamless integration of technology and addressing the diverse needs of learners, all while maintaining course quality and engagement.
- **Integration Challenges**: The difficulties encountered when seamlessly incorporating course materials and activities into the existing learning management system or tools. These challenges can include technical issues and compatibility problems, among others.
- **Time Management Challenges**: Learners may encounter ineffectively allocating and managing their time between online and in-person components of the course. These challenges include balancing work, study, and personal commitments, adhering to deadlines, and maintaining a consistent learning schedule.

10) Self-Learning

Self-learning is also crucial, where employees or professionals can independently acquire new knowledge, skills, and competencies, often beyond their formal educational or training requirements. This proactive approach to learning is essential as industry trends are constantly changing.

Self-learning in industries can take various forms, such as online courses, reading industry-related literature, attending workshops, or seeking mentorship. It empowers individuals to stay competitive, adapt to change, and enhance their contributions within their respective fields, ultimately benefiting both the employees and the organizations they work for.

Additionally, among the various learning formats identified, it is important to note that specific training formats were excluded from our discussion due to their limitations. We found that these excluded formats were found to be less evolved, ineffective, relatively unpopular, or can be implemented in the above-identified learning formats. Our research focused on learning formats that have demonstrated effectiveness, relevance, and widespread adoption in the field. It includes Homemade Video Campaign, Fishbowl, Informal Training, Mobile Training, Job Rotation, Programmed Instruction, Teaching in a Factory, Peer-to-Peer Training, Learning via Temporary Promotion, Vestibule training, Learning in tandem, Learning via Networking, Learning via MR/XR technologies, among others.

4.1.2 Clustering of LFs based on their key characteristics

After identifying the learning formats, the next step is determining their characteristics, allowing us to group them accordingly. Several references provide classifications for these formats. For example, PROHASKA [Pro21, p.31] defines communication types as formal and informal for certain learning programs. Additionally, she specifies the duration of learning programs and the number of people involved in each program [Pro21, p.30].

KAUFFELD provides definitions for various learning types, categorizing them as formal and informal. Additionally, KAUFFELD outlines that some learning programs are team-based while others are individually oriented. The programs are further categorized based on the medium type, such as online or offline delivery methods. Furthermore, the book presents various methods for enhancing these programs, including strategies for blending learning modalities and planning seminars by incorporating videos, 3-D imagery, and other multimedia elements [Kau10, p.24].

The concept of "New Learning" is defined by ZEUCH [Zeu16, p.300], where he categorizes learning into various dimensions, including formal-informal learning, individuality, and synchronous-asynchronous communication. Additionally, the literature provides definitions for the methods used in designing learning formats, termed "Learning Methods."

After a thorough examination of the existing literature, learning formats have been clustered into five distinct groups. It includes:

1) **Mode of Delivery**: When determining the learning format, it is vital to specify how the program will be delivered to the participants. There are three available delivery options, which encompass online, offline, and hybrid approaches.

    - Online: This approach involves delivering the program through digital platforms, allowing participants to access the content remotely and engage in virtual (V-Learning) or e-learning.
    - Offline: Offline delivery relies on traditional methods, such as in-person classes or printed materials, where participants physically attend sessions or receive hardcopy materials that include seminars.
    - Hybrid: The hybrid approach combines online and offline elements, offering participants a flexible learning experience combining digital resources with in-person interactions, creating a well-rounded educational experience.

2) **Communication Type**: It constitutes a crucial element upon which the effectiveness of the learning format relies. Effective communication, both among participants and between participants and instructors, plays a pivotal role. Therefore, communication is classified into three types: synchronous, asynchronous, and hybrid.

    - Synchronous communication: It involves real-time interactions among participants and instructors, enabling immediate exchange of information and feedback. A seminar is one of the most suitable formats for synchronous communication.
    - Asynchronous communication: It allows for flexible interactions as participants and instructors engage at different times, making it suitable for self-paced learning. It often involves communication via emails, forums, or other text-based platforms.
    - Hybrid communication: It combines elements of both synchronous and asynchronous modes, providing a balanced approach that accommodates various learning preferences and schedules.

3) **Collaboration Type**: A learning program typically contains various ways in which learners engage with each other. The choice of collaboration type often depends on the learning objectives, the content's characteristics, and the intended learning results within the learning program. There are three types of collaboration, working individually, in a team, and in a group.

    - Group Participation: Learners collaborate collectively in larger groups, fostering cooperation, various perspectives, and collective problem-solving. In a seminar or webinar, participants can be split into groups for exercises.
    - Individual Participation: Learners work independently on their tasks, promoting self-reliance and self-discipline, with interactions limited to seeking assistance when necessary. In web-based training, individual exercises are incorporated to enhance this independent learning approach.
    - Team Participation: Learners collaborate in smaller teams, combining elements of group and individual work, offering a balance of shared objectives and personalized communication.

4) **Number of Participants**: Learning programs vary in the number of participants. For seminars, the participant count typically ranges from 8 to 20. In contrast, for formats such as web-based training or live online events, there are no set limits on the number of participants. The selection of the learning format highly depends on the number of participants. Based on that, we defined the following types:

    - Individuals: As previously discussed, this sub-type involves a single participant working independently.
    - Pairs: This sub-type includes two participants collaborating or learning together, often in pairs. It promotes close interaction and peer support. Mentorship is an excellent example of such participation.
    - Small Groups: In this sub-type, a small group of participants, typically ranging from three to six individuals, collaborates on tasks or projects. It encourages teamwork and group dynamics. Coaching is also an effective format for small groups.
    - Medium Groups: This sub-type involves a medium-sized group, often between seven to twelve participants, working collectively. It allows for more diverse perspectives and responsibilities. Seminars and webinars are good examples of such formats.
    - Large Groups: It encompasses larger groups of participants, typically more than 100 individuals. Large group participation is expected in live online events and web-based learning and may involve minimal interaction among participants.

5) **Learning Types:** Learning is often considered formal or informal. One can also define it by adding one more type as non-formal. Formal and informal are two distinct approaches to acquiring knowledge, skills, values, and understanding. Both types of learning are valuable and complement each other in an individual's lifelong learning journey. Below, both types are defined:

    - Formal Learning: It refers to structured, organized, and systematic educational experiences. It often occurs within established institutions. It is characterized by a predetermined curriculum, specific learning objectives, assessments, and recognized certifications upon successful completion. It is typically led by instructors or educators and follows a planned and regulated format.

- Informal Learning: These learnings are spontaneous and unstructured. It occurs through daily life experiences, interactions, and self-directed exploration. A set curriculum or assessment does not bind informal learning, and it often takes place outside traditional educational settings. It can involve activities such as self-study, observing others, trial and error, on-the-job learning, and absorbing knowledge from one's surroundings.

There are five groups considering various aspects of LFs, as described above. These five groups are defined in the top column of the table in Table 4.2, with LFs listed on the left side of the table.

Learning Format	*Mode of Delivery*	*Collaboration Type*	*Number of Participants*	*Learning Types*	*Communication Type*
Seminar	Offline	Groups / Teams	< 15	Formal	Synchronous
Mentoring	Hybrid	Individuals	1	Hybrid	Hybrid
Coaching	Offline	Individual / Groups	2 - 15	Hybrid	Synchronous
Game-Based Learning	Hybrid	Groups / Teams	< 10	Formal	Synchronous
Computer-Based Training	Offline	Individual	100 +	Formal	Asynchronous
Conferences	Hybrid	Groups	100 +	Formal	Hybrid
Web-Based Training	Online	Individual	100 +	Formal	Asynchronous
Webinar	Online	Groups	100 +	Formal	Synchronous
Blended Learning	Hybrid	Groups / Teams	10 +	Formal	Hybrid
Self-Learning	Hybrid	Individual	1	Hybrid	Asynchronous

Table 4.2: Clustering of LFs based on 5 types

Each LF is accompanied by an explanation of these types, primarily drawing from the literature defined in Chapter 3.2.1. Additionally, the LF “Self-Learning” is incorporated into the cluster, given its crucial importance as a form of learning where SE practitioners are self-motivated to acquire knowledge. This learning mode primarily relies on informal methods and allows individuals to explore and develop their skills without the constraint of time limitations.

4.1.3 Designing of posters to define LFs

After finalizing the learning formats and defining their characteristics, the following step involved their formal definition and further explanation, a way we used named "Academic Posters." For each selected learning format, we designed academic posters.

As defined by GUNDOGAN [GKK+16] and [Lib20-ol], academic posters serve as a visual medium for conveying information, seamlessly integrating text and graphics. They play a significant role in presenting one's work at conferences, enabling the clear definition and display of LFs specific to systems engineers. These posters play a crucial role in communicating complex concepts and research results to a broader audience in an engaging and easily understandable way.

The following information could be included in the poster, in addition to other details relying on the topic:

- **Heading**: The primary title of the poster that defines the subject.
- **Introduction**: A brief introduction about the topic the poster aims to address.
- **Method**: Inclusion of the method(s) in the poster that focuses on the goals we are aiming to achieve.
- **Results**: The results and key findings can also be integrated into the poster.
- **Conclusion**: A concise summary of the topic addressed in the entire poster.
- **Reference**: Provide sources from which the topic information has been gathered.

Figures 4-2 and 4-3 depict the poster for a learning format named "Seminar". The zoomed versions of the poster's left and right sides are presented in Figures 4-2 and 4-3 on the following page.

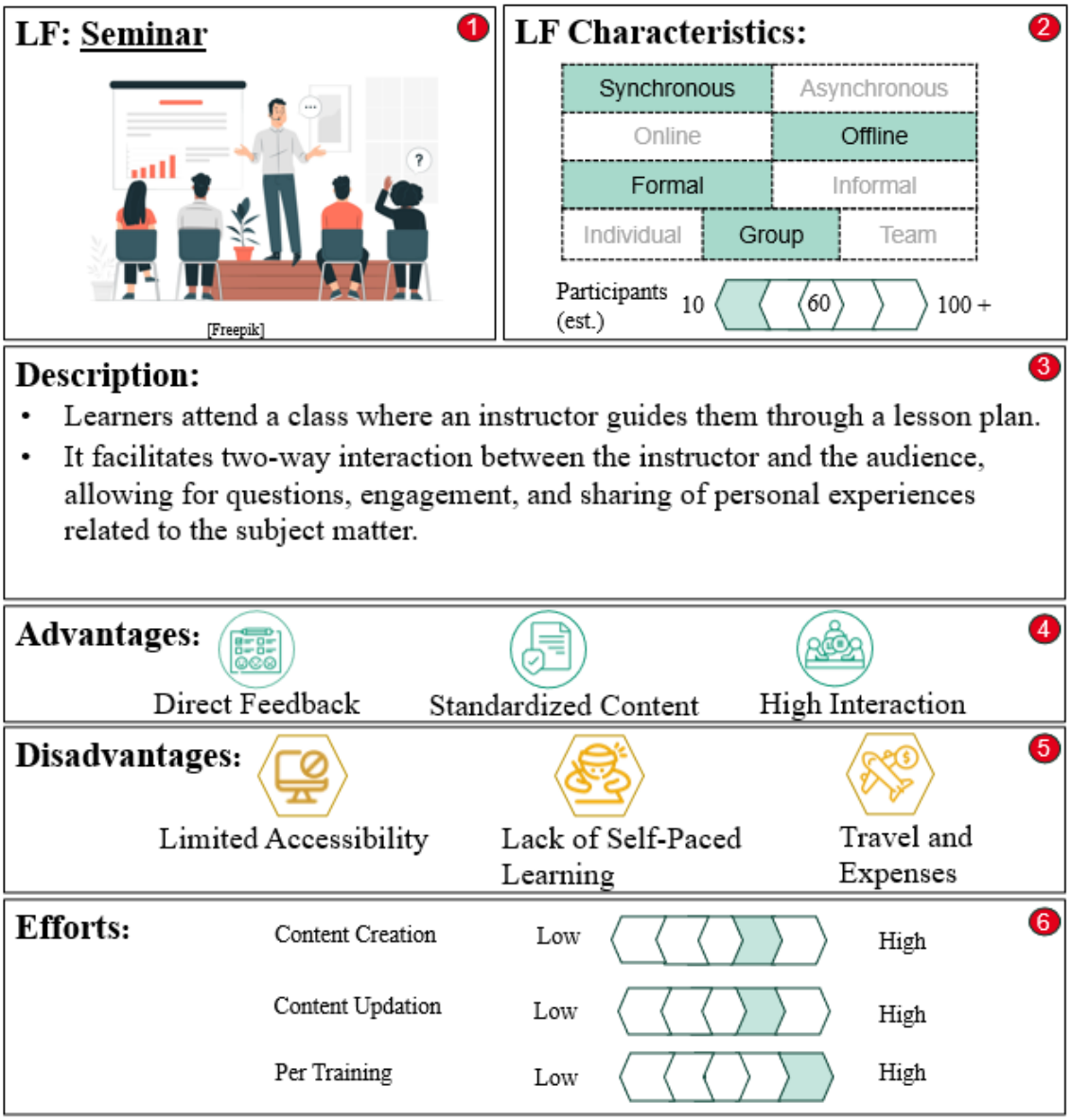


Figure 4-2: Left half of the poster of the LF seminar

Let's break the poster "Seminar" defined in Figure 4-2:

- **Name of the learning format**: As the name itself suggests, the name of the LF is provided here, accompanied by an image to enhance visual appeal. In the top-right corner, numbers are displayed to indicate the flow of the poster.

  LF Characteristics: The characteristics of the poster are also presented in the form of a table. The characteristics present in the LF are denoted as colored cells with a strong outline, while those missing have cell outlines denoted as dotted lines with no color.

  The seminar features four characteristics, as explained in detail in Chapter 4.1.2:

  1) Synchronous communication: Participants can interact with each other and with the trainer as well.
  2) Offline: The training is in-person.
  3) Formal: The formal learning approaches are used within the training.
  4) Number of Participants (estimated): The metric used here ranges from 10 participants to 100+ because some formats typically have 10 or fewer participants, such as seminars, while others may have a large number of participants, such as web-based training or conferences. The number of participants significantly affects the efforts before and during the training.

- **Description**: This section briefly introduces the LF primarily sourced from the referenced material.
- **Advantages**: To illustrate the benefits of the LF, a visual approach is employed using icons related to each specific advantage. In cases where certain formats share similar key advantages, the same icon is utilized along with its corresponding title. These advantages are concisely explained at the start of the file, providing a convenient overview of all the benefits in one place. It's important to note that there may be additional benefits that are not included in the posters.
- **Disadvantages**: We used icons with titles similar to the advantages to represent the limitations, and these were concisely explained at the beginning of the LFs. These limitations highly affect the selection of a LF for the desired SE competency.
- **Efforts**: The last section of the left-side poster is titled efforts (of instructor) and is further explained in three categories, namely:

1) Content Creation: This metric represents the level of effort the trainer requires for course planning and development. For certain learning formats, this process can extend over several months. We utilize a '1-5' scale to gauge effort, with '1' indicating low effort and '5' signifying high effort. In the seminar poster, this effort level is indicated by filling the metric section with color, and it is rated at '4'. This rating is due to the seminar's specific focus on particular topics or company requirements, necessitating careful planning and development of the program.

2) Content Updation: It represents the efforts required to update the content of the format. Sometimes, it takes less time to update the content of formats such as web-based training, but content creation is more extensive in such cases. In the case of seminars, as mentioned above, the updating cost remains consistent because seminars typically concentrate on company-specific requirements, and trainers have to work on both content creation and updating tasks.

3) Per Training: It denotes the efforts needed during the training, and this can vary based on factors like the number of participants, how the content is delivered, length of the training, training strategies, training included forms and any tools or aids used in the training.

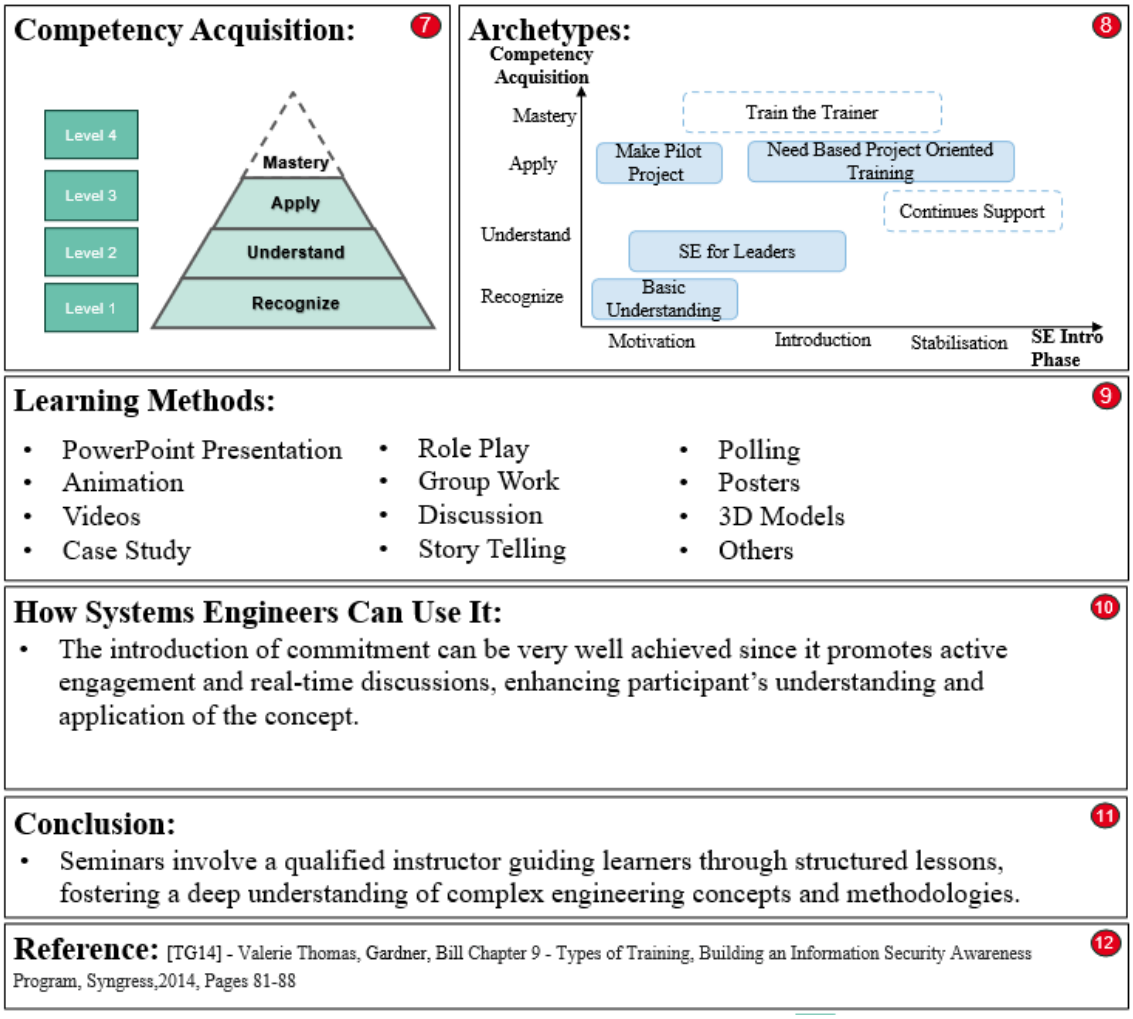


Figure 4-3: Right half of the poster of LF seminar

The right side of the poster starts from the sixth section, as shown in Figure 4-3. We will further explain the remaining sections below:

- **Competency Acquisition**: The competency levels are defined in Chapter 3.1.5, where the maximum level one can achieve is "Mastery," and "Recognize" is for basic understanding. Competency levels are determined for each format, indicating the highest level a format can effectively support. In Figure 4-3, one can achieve competencies up to the "Apply" level when using a seminar. A seminar is ineffective for achieving mastery in any competency, but it can be combined with other formats.

- **Archetypes**: A brief introduction is provided in Chapter 3.1.7 about the SE archetypes. In the posters, we used them to demonstrate which learning format(s) can be used to provide training according to each archetype. For example, a seminar alone is ineffective for the "Train the Trainer" and "Continues Support" archetypes, but it is well-suited for the other five archetypes.
- **Learning Methods**: Various elements can be incorporated to enhance the training. For example, a seminar might include elements such as a PowerPoint presentation, animations, videos, and case studies to make the training more effective, interactive, and immersive for the participants.
- **How Systems Engineers Can Use It**: Once the learning format has been formally defined, the next step involves defining them for systems engineers. SE Characteristics, as outlined in Chapter 4.2.1, can be utilized for this purpose. We have established SE characteristics that can be attained through each learning format, providing a foundation for defining LFs for SE. For instance, a seminar brings practitioners together in training, fostering commitment, which is one of the SE characteristics.
- **Conclusion**: As the name suggests, this section provides a summary to conclude the poster.
- **Reference**: The final section provides information about the sources from which LF-related information has been derived. Please note that this reference section may not apply to all other sections.

The comprehensive list of designed posters for the finalized learning formats is presented in "Appendix A3."

4.2 Identifying the characteristics for selecting LFs in SE

After identifying and formally defining the learning formats, the following step involves categorizing them into clusters, each representing various types. Once the clustering process is completed, the next phase entails defining these formats in the context of SE competencies. To achieve this, we must initially identify the key characteristics of SE and then determine the relevancy of each format for the respective learning formats. This allocation ensures that a specific learning format effectively addresses the particular aspects essential for SE. Therefore, it is imperative to establish SE-specific characteristics for each learning method. The principles explained by MUNDT et al. [MWA+23], mentioned in Chapter 3.2.2.1, serve as a significant source of information.

4.2.1 Identifying and defining the learning characteristics for SE

To define the aspect of SE within the learning format, we need to identify the SE-specific characteristics that can be achieved through these formats. The principles of systems engineering, as defined by MUNDT et al. [MWA+23, p.3], were taken into consideration. A selection was made by choosing various aspects and validating them with expertise.

4.2.1.1 Identifying possible learning characteristics for SE

In identifying these characteristics, the fundamental question is, “What types of requirements for the learner can be derived from these characteristics?” It is essential to base these characteristics on the LF itself rather than on the specific content that will be delivered during the training via that LF.

The five characteristics are defined alongside other traits that are not specified for SE but are common and have not been taken into consideration. Let’s first review the ones that have not been selected, and then we will examine the ones that are later used in the learning formats.

The characteristics that are not selected from the 12 principles include:

- Reuse and Standardization: An essential principle lies in the reutilization of solution knowledge and requires investing in the SE infrastructure through the standardization of processes, tools, and interfaces. This principle can be effectively taught by incorporating its characteristics in the planning of content delivery material rather than focusing solely on the LF itself.
- Decision Based on Risk and Evidence: Effective decision-making necessitates the prioritization of options and the systematic analysis of trade-offs. Additionally, decision-makers must proactively anticipate future needs and carefully navigate the complex trade-offs between cost, schedule, performance, and risk. The goal can be achieved by incorporating these aspects into the learning format.

- Early Validation and Verification: Two processes can be delineated within exercises of a learning format, showcasing the differences in early validation and verification. Consequently, this depends on the content that must be taught to learners rather than on the learning method itself.
- Interface Management: The primary goal of interface management is to minimize complexity by reducing and simplifying the interactions between various components, subsystems, or elements within a complex system through the concept of loose coupling. As it can be taught by adding content based on interface management, it is less applicable to the learning format but can be achieved by various programs.
- Documentation: It is an essential component that can be taught through any LF where specific standards are defined for documentation. However, it is more relevant to the content of the LF than to the LF itself.
- Effectiveness over Efficiency: The primary objective is to maximize value with the resources at hand rather than solely focusing on cost reduction. This objective can be achieved through content focused on effectiveness and is more applicable to various programs than to the learning format itself.
- The principles “Iteration and Adaptability,” “Complexity to Manage Complexity,” and “Top-Down and Upfront Development” are the three other principles that are important for systems engineers but can be taught using methods in learning arrangement as for development, frontloading is essential where the focus is putting a strong emphasis on early-stage analysis is pivotal for gaining a comprehensive understanding of requirements or issues before diving into the design process.

Two of the aspects of systems engineering, as repeatedly defined in INCOSE [INC23, p.66], are “Faithfulness” in SE practice and “Trustworthiness” [INC23, p.66] where the goal for SE practitioners is to ensure that system or subsystems function correctly, operate punctually, and are available when required. These aspects can be taught through any LF and are more related to the content rather than being specific to any learning format(s). These aspects can be considered core values but might not be suitable for defining SE characteristics.

Based on the above analysis and in conjunction with the experts, the **five** characteristics below are defined for the SE qualifications that are further used in the learning formats:

- Mindset
- Commitment
- Transdisciplinary
- Holism
- Stakeholder-Centricity

These characteristics are further explained below in Chapter 4.2.1.2, providing a concise yet detailed exploration of each aspect.

4.2.1.2 Defining relevant learning characteristics for SE

This chapter provides a comprehensive overview of all five finalized characteristics. These characteristics will be used in planning LFs and in defining the relationship between SE competencies and identified LFs.

Below are the identified five characteristics:

- **Mindset:** For the introduction and qualification of Systems Engineering, the Mindset plays an important role. SE practitioners must keep an open mind and revise decisions in response to newly acquired data, improved methods, optimized processes, or other relevant factors, ultimately leading to better system outcomes and performance. LFs and learning arrangements should consider that changing a mindset needs time. There should be enough time and space given to the practitioners as the change of mindset cannot be achieved in a short duration.
- **Commitment:** A successful implementation of SE needs the commitment of all stakeholders. Encouraging collaborative environments within groups and multidisciplinary teams fosters a sense of commitment and shared goals. This commitment is further strengthened through transparent communication, regular progress assessments, and a shared dedication to achieving the project's objectives. Commitment can be further enhanced by holding regular meetings involving teams, customer representatives, and project leaders.
- **Transdisciplinary:** The learning format(s) shell ensures the interdisciplinary characteristic that multiple methods can achieve. One such method is "discussions," which bring together a multidisciplinary team for conversations. Such discussions involve various disciplines, and the choice of format depends on the nature of the conversation.
- **Holism:** The learning format(s) shell ensures the holism characteristic of SE by providing the relevant information efficiently across all the disciplines, which plays an essential role in understanding the impact of changes. The information might be related to various aspects such as management, technical knowledge, employee qualification, etc.
- **Stakeholder-Centricity:** The learning format(s) shell ensures the stakeholder-centricity attribute of SE. It can be achieved by understanding the needs or expectations of stakeholders involved in the project. Interaction is an essential aspect of stakeholder centricity, which includes engaging with and involving individuals, groups, or entities with an interest or influence in a project.

4.2.2 Define a link between SE characteristics and LFs

After defining the LFs and the SE characteristics, the next step is to establish the connection between the two. The key source for understanding the LFs is presented in Chapter 3.2.1, while the SE principles, as defined by MUNDT et al. [MWA+23, p.3] that are further explained in Chapter 4.2.1, were used to describe the SE characteristics.

Subsequently, the task is to identify the relationship between the SE characteristics and the LFs, with the goal of determining which LFs are best suited for specific characteristics. This is best accomplished through a comprehensive review of the existing literature, inferential analysis, and expert evaluations for validation.

The mapping is typically represented as a matrix, which ultimately enables us to assess the significance of specific LFs for particular characteristics. This information can serve as a valuable resource for addressing future requirements and making informed decisions.

The primary objective of this mapping process is to determine which format(s), or combinations of formats, are most suitable for achieving specific SE characteristics.

Mapping of SE Characteristics with the Learning Formats Mapping Scale: 0 = Not Achievable 2 = Partially Achievable 4 = Fully Achievable	**Learning Formats**									
	Seminar	**Coaching**	**Mentoring**	**Game-Based Learning**	**Computer Based Learning**	**Conference**	**Web Based Learning**	**Webinars**	**Blended Learning**	**Self-Learning**
Mindset	2	4	4	2	0	2	2	2	4	2
Commitment	4	4	4	2	0	2	0	2	4	0
Transdisciplinary	4	2	0	4	2	2	2	2	4	0
Holism	2	2	2	2	2	0	4	2	4	4
Stakeholder Centricity	2	2	2	2	4	2	4	2	4	2

Table 4.3: Mapping of SE characteristics to the LFs

As depicted in Table 4.3, the first column describes the characteristics, followed by the learning format. The metric employed consists of three levels:

0, denoting "**Not Achievable,**" signifies that the SE characteristics 'X' cannot be accomplished by LF 'A.'

In contrast, a **2** on the metric signifies "**Partially Achievable,**" implying that Characteristics 'X' might be attainable using LF 'A,' but the results may be less favorable or require a combination with other formats to enhance training effectiveness.

Finally, **4** signifies the "**Achievable,**" which means that the LF is suitable for achieving the SE characteristic(s).

Let's take an example to understand these three levels further. In Table 4.3, the characteristic "Mindset" has a value of 4, defined for the LF "Coaching." This means that to change the mindset of an employee, coaching is one of the most suitable ways to plan the training. Changing one's perspective is a slow and time-consuming process, and coaching and mentoring are more ideal than a seminar for the same reason. Conversely, for the same characteristic, it is mentioned that "Computer-Based Training" is not helpful because communication is asynchronous, and the training is considered to be less interactive and

generally carried out individually. These reasons make it less favourable than other formats.

The values 0, 2, and 4 are assigned to create a mapping or a characteristics-LFs matrix, referred to as the "Matrix: $A_{C\text{-}LF}$." This mapping provides an overview of which SE characteristics are better suited for specific qualifications compared to others. The finalized results will be further used to map LF and SE competencies.

4.2.3 Define a link between SE competencies and LFs

A total of 36 SE competencies were defined by the INCOSE competency framework [BGD+18, p.9]. These 36 competencies were subsequently analyzed and reconfigured into 16 core competencies by KÖENEMANN et al. [KWA+22, p.5]. These 16 core competencies form the basis for defining the LFs that facilitate the acquisition of knowledge and skills necessary to excel in these competencies.

While there is no direct link between the SE competencies and the learning formats, our approach incorporates a three-step method. This method serves as a bridge, facilitating the alignment of SE competencies with suitable learning formats. The three steps outlined below provide a structured framework for achieving this alignment and ensuring that the chosen learning formats effectively address the desired SE competencies.

Step 1: In the initial step, we systematically analyze the 16 SE competencies and define a corresponding characteristic for each one. This is achieved by creating a mapping matrix that establishes the relationships between the SE competencies and the identified SE characteristics. Such an approach is instrumental in providing a structured framework for understanding and reinforcing the connection between competencies and their associated characteristics.

Step 2: The second step involves establishing a linkage between LFs and SE characteristics, as previously elaborated in Chapter 4.2.2. This mapping matrix offers a comprehensive view, demonstrating that if SE practitioners aim to acquire a specific characteristic, such as a "mindset," they can achieve this through the utilization of one or a combination of learning formats, which include options like "seminars" and "blended learning." This strategic connection enhances the efficiency of aligning qualifications with the desired SE aspect.

Step 3: Building on the information derived from Steps 1 and 2, we obtain two distinct matrices. In Step 1, Matrix 'A' emerges, comprising 16 rows representing competencies and 5 columns for characteristics. In Step 2, Matrix 'B' takes shape, containing 5 rows for characteristics and 10 columns for learning formats. These matrices lay the foundation for the creation of Matrix 'C' through matrix multiplication, resulting in a matrix with 16 rows representing competencies and 10 columns representing learning formats. The successful derivation of Matrix 'C' enables us to establish the relationships between SE competencies and learning formats, allowing for a more informed determination of which competency is best suited for which learning format or combination of formats.

4.2.3.1 Mapping of SE competencies with the SE characteristics

This chapter will map the SE characteristics defined in Chapter 4.2.2 to the 16 competencies defined by KÖENEMANN et al. [KWA+22, p.5]. The results of this mapping will serve as a critical link in establishing the relationship between LFs and SE competencies, offering valuable insights into how these two align and interact.

In Table 4.4, 5 SE characteristics are added in the columns, and 16 SE competencies are added to the table in the rows. For the mapping, we are focusing on the question of whether to achieve the competency 'X,' do we need the characteristics 'A' in the LF.

The three-level scale shown in Table 4.4 is crucial in this mapping, providing a specific characteristic for each competency. This scale aligns with the one used in Chapter 4.2.2,

'**0'** represents scenarios where the characteristic is irrelevant in achieving the corresponding competency.

On the other hand, '**2'** suggests that the characteristic can be attained, but it may not lead to optimal training effectiveness, especially when combined with different characteristics.

Finally, '**4**' signifies the importance of specific characteristics in achieving competency effectively. This scale offers a comprehensive perspective on the relationship between SE characteristics and the competencies they align with.

Let's take an example, as shown in the figure to develop the competency "Systems Thinking," "Mindset," "Commitment," "Transdisciplinary," and "Holism" are necessary, but the "Stakeholder Centricity" is irrelevant for the competency.

At the end of this mapping process, we obtain a matrix with SE competencies as rows and SE characteristics as columns, referred to as "Matrix: $B_{Co\text{-}C}$." This matrix, labeled "$B_{Co\text{-}C}$," will prove valuable for our discussions in the following subchapters.

Mapping of SE Competencies with the SE Characteristics Mapping Scale: 0 = Irrelevant 2 = Partially Relevant 4 = Relevant		SE Characteristics				
		Mindset	Commitment	Transdisciplinary	Holism	Stakeholder Centricity
Core Competencies	System Thinking	4	4	4	4	0
	LifeCycle Consideration	4	2	4	4	0
	Customer/Value Orientation	4	4	0	2	2
	System Modeling and Analysis	2	0	4	4	2
Social/Personal Competencies	Communication	4	2	2	0	2
	Leadership	4	2	4	4	2
	Self-Organisation	2	2	0	2	0
Management Competencies	Project Management	4	4	4	4	2
	Decision Management	4	2	2	4	2
	Information Management	0	4	0	4	0
	Configuration Management	2	4	4	2	2
Technical Competencies	Requirements Definition	0	2	4	2	4
	System Architecting	2	2	4	4	4
	Integration, Verification, Validation	0	2	4	2	4
	Operation and Support	2	0	2	2	4
	Agile Methods	4	4	2	0	4

Table 4.4: Mapping of SE competencies and SE characteristics

4.2.3.2 Mapping of SE competencies and LFs

The resulting matrix, obtained in Chapter 4.2.2 by mapping SE characteristics and LFs, named matrix "$A_{C\text{-}LF}$," will be valuable in establishing the relationship between SE competencies and learning formats.

Additionally, the matrix resulting from Chapter 4.2.3.1, which involves mapping SE competencies and SE qualification characteristics named matrix "$B_{Co\text{-}C}$," plays a key role in identifying this link. This chapter explores the potential to establish a connection between SE competencies and LFs.

Based on the information from the "$A_{C\text{-}LF}$" matrix and the "$B_{Co\text{-}C}$" matrix, it becomes evident that the identified SE characteristics serve as a bridge. This insight allows us to harness this connection to create a resulting matrix, which we can appropriately name "$C_{Co\text{-}LF}$":

$$\text{Matrix } C_{Co\text{-}LF} = B_{Co\text{-}C} \ * \ A_{C\text{-}LF}$$

Equation 4-1: Matrix multiplication of $B_{Co\text{-}C}$ and $A_{C\text{-}LF}$ to find the resulting matrix $C_{Co\text{-}LF}$

$C_{Co\text{-}LF}$: Matrix C has SE competency as rows and LFs as columns.
$B_{Co\text{-}C}$: Matrix B has SE competency as rows and SE characteristics as columns.
$A_{C\text{-}LF}$: Matrix A has SE characteristics as rows and LFs as columns.
*: Multiplication of two matrix

The resulting matrix "$C_{Co\text{-}LF}$" can be observed in Table 4.5 on the following page, where the rows represent SE competencies, and the columns are dedicated to various LFs. This matrix provides a comprehensive visual representation of the intricate relationships between SE competencies and LFs.

Mapping of SE Competencies with the LFs Mapping Scale: 0 = Irrelevant 2 = Partially Relevant 4 = Relevant		Learning Formats									
		Seminar	Coaching	Mentoring	Game-Based Learning	Computer Based Learning	Conference	Web Based Learning	Webinars	Blended Learning	Self-Learning
Core Competencies	System Thinking	5	5	4	4	2	2	3	3	6	2
	Lifecycle Consideration	4	4	3	4	2	2	3	3	6	2
	Customer/Value Orientation	3	4	4	2	1	2	2	2	5	2
	System Modelling and Analysis	3	3	2	3	2	2	4	2	5	2
Social/Personal Competencies	Communication	3	3	3	2	1	2	2	2	4	1
	Leadership	4	4	4	4	2	2	4	3	6	3
	Self-Organisation	2	2	2	1	0	1	1	1	2	1
Management Competencies	Project Management	5	5	4	4	2	3	4	4	7	3
	Decision Management	4	4	4	3	2	2	4	3	6	3
	Information Management	2	2	2	2	1	1	2	2	3	2
	Configuration Management	4	4	3	4	2	2	3	3	6	2
Technical Competencies	Requirements Definition	4	3	2	3	3	2	3	2	5	2
	System Architecting	4	4	3	4	3	2	4	3	6	3
	Integration, Verification, Validation	4	3	2	3	3	2	3	2	5	2
	Operation and Support	2	2	2	2	2	2	3	2	4	2
	Agile Methods	4	4	4	3	2	3	3	3	6	2
Average		3.6	3.58	3.03	3.1	1.95	2	3.03	2.55	5.1	2.05

Table 4.5: Mapping of SE competencies and LFs

The values are obtained by performing matrix multiplication, dividing the resulting matrix by 10, and then rounding each value to the nearest whole number. Values with a decimal portion of 0.5 or greater are rounded up, while those with a decimal part less than 0.5 are rounded down, resulting in integer values.

From the findings presented in Table 4.5, it becomes clear that “Blended Learning” emerges as the most suitable learning format for developing SE competencies. Additionally, both the “Seminar” and “Coaching” formats demonstrate effectiveness in qualifying individuals across most competencies. This highlights the adaptability of these learning formats in addressing the diverse requirements of SE qualifications.

“Computer Based Learning” is considered one of the least suitable learning methods due to its limitations, such as a lack of direct interaction, reduced engagement, and challenges in providing personalized feedback.

“Self-learning” is undoubtedly valuable, yet it is considered one of the less suitable methods when it comes to qualifications linked to competencies. This is primarily due to the need for structured guidance and interactive experiences that may be lacking in a self-directed learning environment. Therefore, competency-related qualifications often prefer a more guided and interactive approach.

4.3 Methods to develop Learning Arrangement (LA)

Once the LFs have been identified and selected to meet specific requirements, and the SE competencies have been mapped to them, the next step involves methods to develop learning arrangements. This process incorporates the aspects of SE as defined in Chapter 4.2.1. It includes the categorization of learning formats into learning arrangements and the further definition of critical elements that can be included in each format.

The literature referenced in Chapter 3.2.1 serves as a valuable resource for acquiring information about the learning formats and their elements, as well as the learning arrangements defined by KÖENEMANN et al. [KSS+23, p.18].

The process defined by KÖENEMANN et al. [KSS+23, p.2] serves as a foundation for defining the methods to develop Learning Arrangements (LAs). The model consists of five phases/milestones (as explained in Chapter 3.2.3.2), each presenting defined tasks and methods that clarify the respective phase. Once the tasks are fulfilled, the results can be obtained, as defined in the result section of each phase. The five phases are further detailed in the following subchapters.

4.3.1 Requirements and competency assessments

The first phase of the process methods involves gathering requirements and assessing competencies. It is crucial to understand which SE qualification characteristics hold more significance for the company. To achieve this clarity, we have established pairwise comparisons of SE qualification characteristics. This approach aids in identifying the essential characteristics from the beginning. Additionally, it proves beneficial in the early stages to trace the requirements for Learning Arrangements (LAs). This step ensures that subsequent processes are planned accordingly. The following subchapters briefly outline the definitions of LAs. These two tasks are further shown in the below Figure 4-5. These two tasks provide prioritized SE characteristics that are more important to the company and a clear view of the LA(s) requirements.

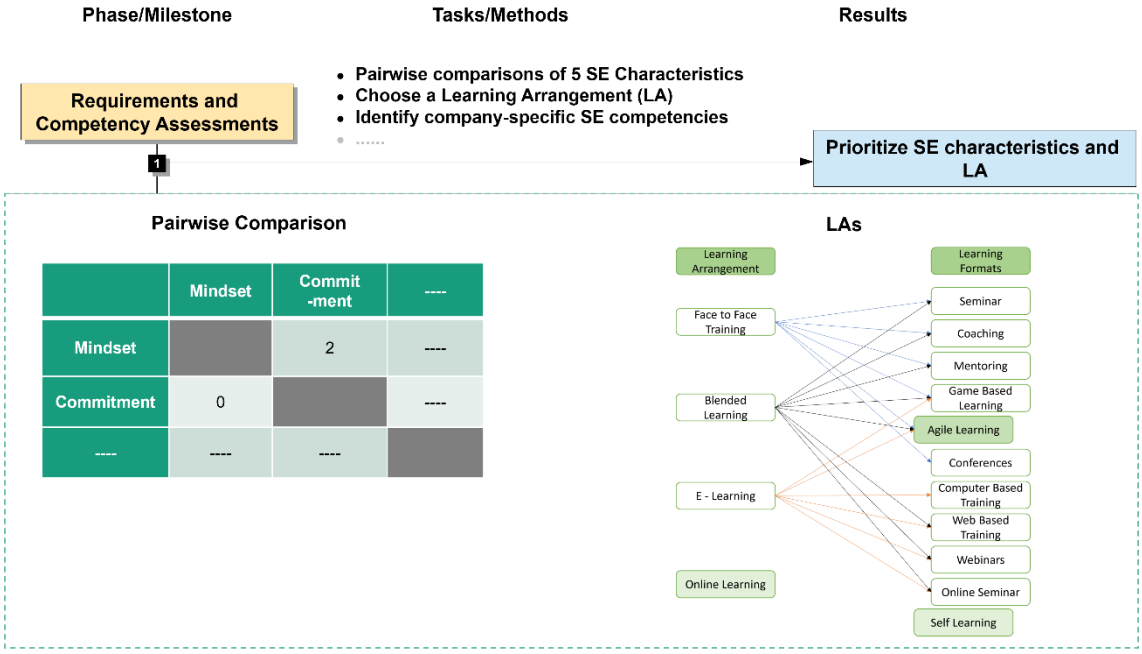


Figure 4-5: Identified tasks for "First" phase

4.3.1.1 Pairwise comparison of five SE characteristics

RAMÍK has defined the pairwise comparisons as a good method that can be used for decision making. It is a method where one assesses each pair to determine preferences or identify any differences between them. This approach is commonly applied in various fields, including the study of selections, social and public choice, and requirements engineering, among others. In the context of multi-criteria decision-making, the pairwise comparison method serves as a useful tool for establishing weighted rankings for alternatives or criteria [Ram20, p.17].

SE characteristics identified in the Chapter 4.2.1.2 can be used to determine which characteristics are more important for the individuals. The comparison is shown in Table 4.6

SE Characteristics 0 Not Important 1 Important 2 Very Important	Mindset	Commitment	Transdisciplinary	Holism	Stakeholder Centricity	Average
Mindset		0	1	2	1	4
Commitment	2		1	1	1	5
Transdisciplinary	1	1		2	2	6
Holism	0	1	0		1	2
Stakeholder Centricity	1	1	0	1		3

Table 4.6: Pairwise comparison of SE Characteristics

The comparison values used are 0, 1, and 2. A value of 0 signifies that individuals are not currently focusing on a specific qualification characteristic, either because it is already present in the environment or not a current priority. A value of 1 indicates that individuals are considering the characteristic but not placing significant attention on it. On the other hand, a value of 2 suggests that the characteristic is very important for individuals or organizations, and they require training that incorporates elements related to that characteristic in the learning formats. This comparison might be different as it depends on individual needs and priorities.

4.3.1.2 Selection of Learning Arrangements (LAs)

To provide an overview of the planning process for LFs to form LAs, the initial step involves identifying the arrangements into which the LFs can be organized. We obtained the information about this arrangement from the references mentioned in Chapter 3.2.1. For example, PROHASKA [Pro21] categorizes training as face-to-face, e-learning, and blended learning. Similarly, KAUFFELD [Kau10], in alignment with Prohaska, employs similar terms like online learning instead of e-learning.

The following three clusters are established for categorizing the Learning Formats:

- **Face-to-Face Learning**: It is often referred to as traditional or in-person learning. It is a conventional method of education where instructors and learners physically gather in a classroom or a specific location. In this format, direct, real-time interaction between the educator and students is a fundamental component. It allows for immediate clarification of doubts, dynamic discussions, and hands-on demonstrations. Face-to-face learning promotes a strong sense of commitment. While it offers valuable in-person engagement, it can be limited by geographical constraints and is often associated with fixed schedules.
- **E-Learning**: Electronic learning is an umbrella term encompassing various forms of education delivered electronically, typically but not limited to the Internet. It is a flexible and accessible approach that allows learners to engage with educational content at their own pace and from virtually anywhere with an internet connection. E-learning is considered an umbrella term for online learning or digital learning as defined by PROHASKA [Pro21].
- **Blended Learning**: It is also known as hybrid learning and combines elements of seminar and web-based training. It integrates traditional classroom settings with digital resources and online activities. This method provides learners with flexibility in terms of both timing and location, enabling them to access course materials conveniently and participate in online discussions, quizzes, or multimedia content while still having opportunities for in-person interaction during scheduled sessions.

Once the LFs are clusters based on their intended learning arrangements. Within each cluster, we can define the specific formats that are utilized. It's important to note that there may be instances where certain formats are repeated multiple times, meaning that the same format is present in different clusters. For example, face-to-face learning formats include LF seminars, coaching, mentoring, and game-based learning.

The overview of the learning arrangement and its relation to the learning formats are shown in Figure 4-6. Further information related to the LFs is explained in detail in Chapter 4.1.1. The term "e-learning" is used as an umbrella term for digital learning and online learning. Similarly, the "self-learning" format goes hand in hand with the other formats, so there is no need to explicitly mention or use it for a specific learning arrangement. Similarly, "agile learning" practices can be used with all of the arrangements.

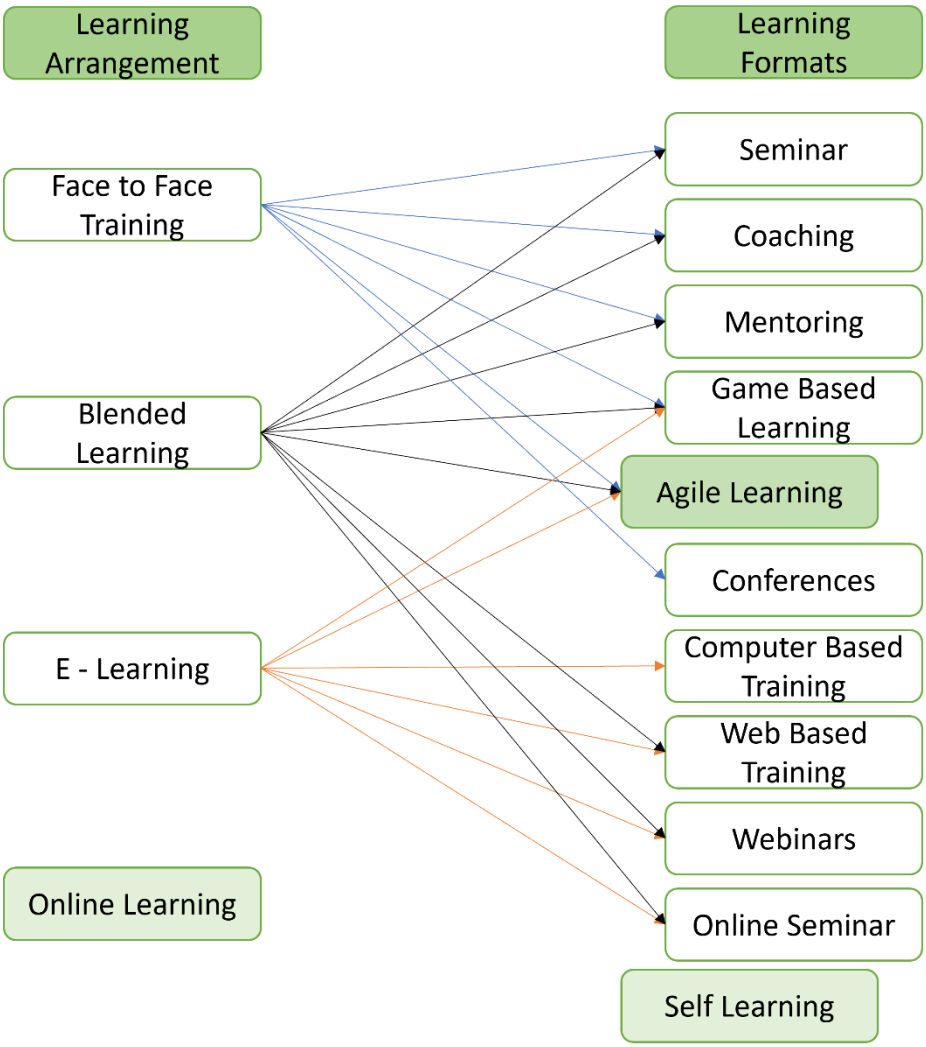


Figure 4-6: Learning arrangements having LFs

The identified company-specific SE competencies will be further utilized in Chapter 4.3.3.4. The task here involves identifying these competencies in the early stages (in requirements) and subsequently using them to recommend LFs.

4.3.2 Clarify scope

In the second phase of the process methods, the focus shifts towards clarifying the scope of qualifications in the context of SE. This involves identifying and addressing challenges inherent in SE qualification, such as interdisciplinary collaboration, mindset shifts, and adaptation to change, among others ([KSS+23, p.13]).

To tackle these challenges effectively, it becomes crucial to define learning formats that not only address these challenges but also provide learning features. Chapter 4.2.1.2 delves deeper into these challenges, articulating them as characteristics. Subsequently,

these five characteristics are integrated with learning formats, ensuring a comprehensive approach to overcoming the hurdles posed by the dynamic field of systems engineering.

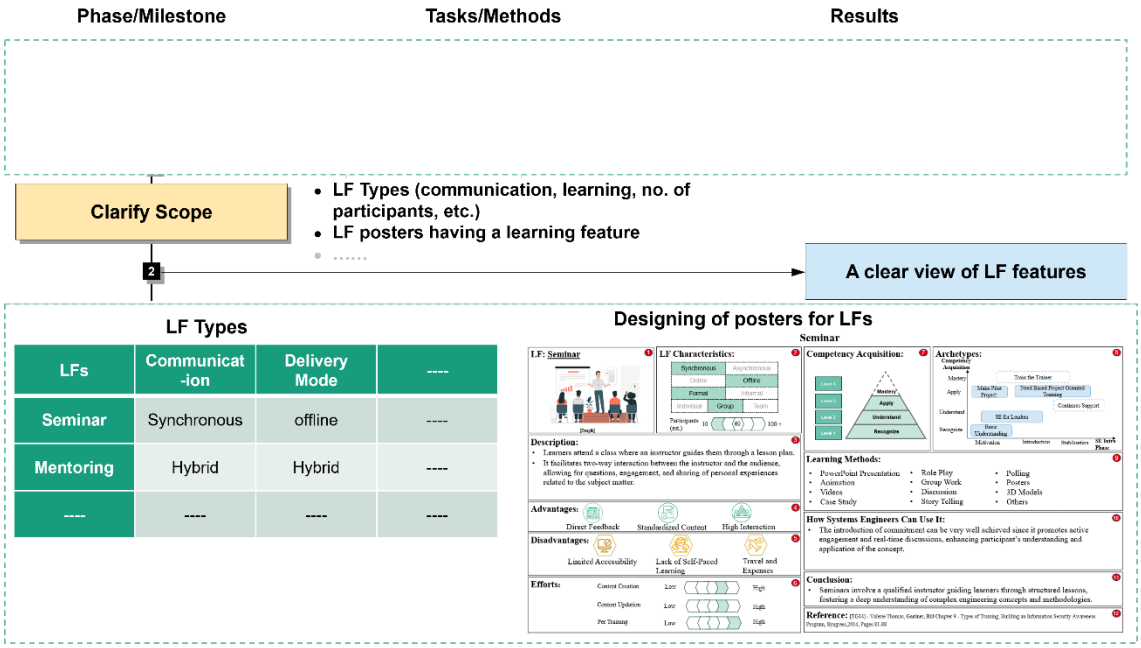


Figure 4-7: Identified tasks for the "Second" phase

These two tasks are also depicted in Figure 4-7, highlighting LF types/characteristics and the posters containing the features of LFs and SE qualification characteristics. The ultimate objective of these tasks is to obtain a clear understanding of LF features, enabling their selection and incorporation into training planning in the subsequent phases of the process methods.

4.3.2.1 Types/characteristics of LFs

The five learning types, encompassing delivery modes (online/offline/hybrid), collaboration types (individual/group/teams), participant numbers ranging from 1 to 100+, and learning types categorized as formal/informal/hybrid, along with communication modes identified as synchronous/asynchronous/hybrid, are clearly defined for each learning format. This detailed categorization helps streamline and enhance the clarity of training scopes. For an in-depth understanding of these learning types, refer to Chapter 4.1.2.

4.3.2.2 Posters of LFs

Learning formats for SE qualification are presented in the form of visually appealing posters designed to consolidate various features in one place. These posters serve as valuable tools in SE qualification planning, offering insights into different aspects of qualification. Further details about the learning formats can be found in Chapter 4.1.1.

The posters are segmented into 12 sections, each providing additional information for a comprehensive understanding of the format. This includes insights into planning, selection, and critical features such as competency acquisition, archetype suggestions, and various efforts, among others.

4.3.3 Conception and production from SE qualifications

The third milestone in the process methods is the "Conception and Production of SE Qualification," as illustrated in Figure 4-8. When conceptualizing the LF, it is essential to consider the archetypes defined by KÖENEMANN et al. [KSS+23, p.21].

It is crucial to consider the potential benefits the organization seeks from the training during the format planning, aligning with the training objectives. Therefore, a pairwise comparison has been employed, utilizing the advantages of the identified learning formats in this thesis. Organizations can select what is most important to them in the pairwise comparison of LF advantages. This process helps integrate the selected LFs into the training, resulting from comparisons between different advantages.

The competencies obtained in the requirements phase also contain the required SE Competencies. LFs can be recommended and planned in this phase by utilizing these competencies.

One additional task has been included because it is crucial to determine the possible learning elements that can be added to a learning format to maximize training results. Therefore, specific learning methods have been defined for the identified LFs, aiding in the planning of learning formats. This step ensures a comprehensive understanding of how to structure the learning experiences within each format for optimal training outcomes. These four tasks are elaborated upon in the following subchapters.

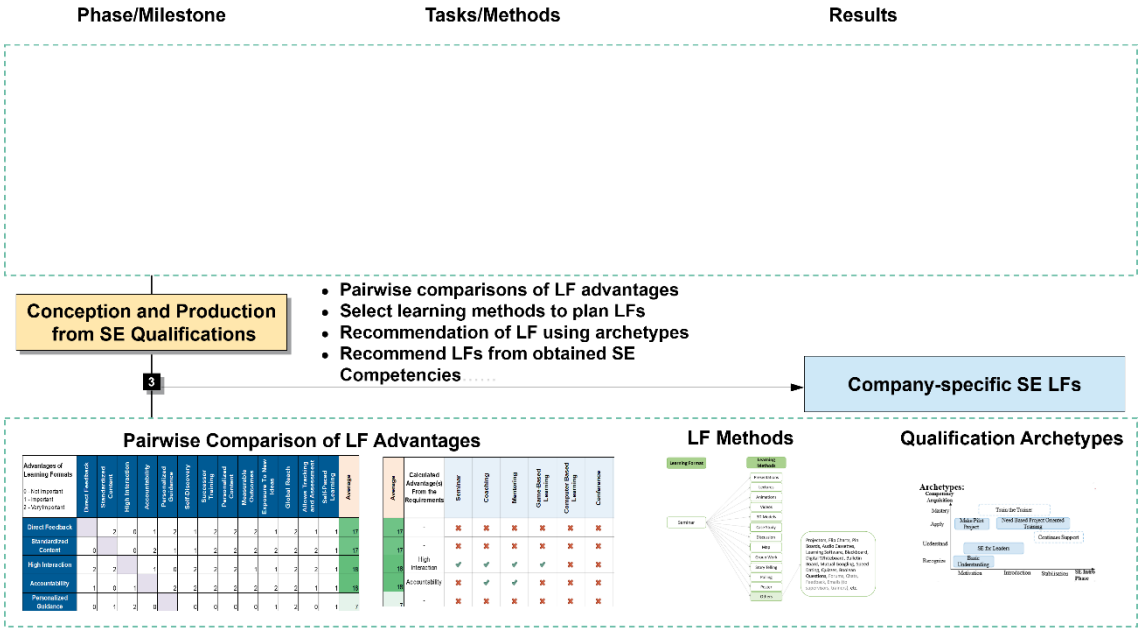


Figure 4-8: Identified tasks for the "Third" phase

The identified tasks are outlined in Figure 4-8 within the process method. This planning and production process results in company-specific LFs. This customization ensures that the LFs align with the company's needs and requirements, optimizing the qualification process's effectiveness.

4.3.3.1 Recommendation of LFs using pairwise comparison of advantages of LFs

In the Chapter 4.1.1, for every LF possible advantages are defined. Based on those advantages, a pairwise comparison has been formulated that helps to plan the learning arrangement.

The advantages help individuals make decisions about which factors are more crucial for their training needs. By considering the maximum sum obtained in the "Average" columns, the comparison provides insights into the recommended LFs, as depicted in Table 4.7 on the following page.

Advantages of Learning Formats 0 - Not Important 1 - Important 2 - Very Important	Direct Feedback	Standardized Content	High Interaction	Accountability	Personalized Guidance	Self-Discovery	Successor Training	Personalized Content	Measurable Outcomes	Exposure To New Ideas	Global Reach	Allows Tracking and Assessment	Self-Paced Learning	Average	Calculated Advantage(s) From the Requirements
Direct Feedback		2	0	1	2	1	2	0	0	1	2	1	1	13	-
Standardized Content	0		0	2	1	1	2	0	2	0	2	2	1	13	-
High Interaction	2	2		1	0	2	2	2	1	1	2	2	1	18	High Interaction
Accountability	1	0	1		2	2	2	2	2	2	2	1	1	18	Accountability
Personalized Guidance	0	1	2	0		0	0	0	0	1	2	0	1	7	-
Self-Discovery	1	1	0	0	2		0	1	2	2	0	1	1	11	-
Successor Training	0	0	0	0	2	2		1	2	1	1	2	0	11	-
Personalized Content	2	2	0	0	2	1	1		1	2	1	2	1	15	-
Measurable Outcomes	2	0	1	0	2	0	0	1		1	2	1	1	11	-
Exposure To New Ideas	1	2	1	0	1	0	1	0	1		1	2	1	11	-
Global Reach	0	0	0	0	0	2	1	1	0	1		0	0	5	-
Allows Tracking and Assessment	1	0	0	1	2	1	0	0	1	0	2		0	8	-
Self-Paced Learning	1	1	1	1	1	1	2	1	1	1	2	2		15	-

Table 4.7: Pairwise comparison of possible advantages of identified LFs

The results of these pairwise comparisons are presented as the recommended LFs, as shown in Table 4.8 on the next page.

Average	Calculated Advantage(s) From the Requirements	Seminar	Coaching	Mentoring	Game-Based Learning	Computer Based Learning	Conference	Web Based Learning	Webinars	Blended Learning	Self-Learning
13	-	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
13	-	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
18	High Interaction	✓	✓	✓	✓	✗	✗	✗	✓	✓	✗
18	Accountability	✗	✓	✓	✗	✗	✗	✗	✗	✓	✗
7	-	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
11	-	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
11	-	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
15	-	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
11	-	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
11	-	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
5	-	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
8	-	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
15	-	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗

Table 4.8: Suggested LFs based on the pairwise comparison and defined advantages of LFs.

The green tick indicates that the LF(s) can be employed for training based on the requirements derived from pairwise comparisons and the predefined advantages outlined in Chapter 4.1.1.

For instance, in Table 4.8, considering the obtained requirements from the pairwise comparison, the highest sum of 18 corresponds to the advantages of “High Interaction” and “Accountability.” These advantages are then compared with another table that outlines the advantages associated with each LF. After these two comparisons, the above table suggests the LFs suitable for the training.

4.3.3.2 Overview of the planning of a LF using Learning Methods (LMs)

Once the learning formats have been chosen, the detailed design phase begins. This entails carefully structuring the preferred format to optimize the learning experience.

For instance, in the case of a seminar, this involves planning specific elements such as exercises, tutorials, lectures, and learning assessments. Each component is thoughtfully designed to align with the intended learning outcomes, ensuring that the seminar effectively imparts knowledge and fosters a rich educational environment. This LF planning stage is essential in tailoring the format to meet the specific needs and goals of the learners, ultimately enhancing the overall educational effectiveness.

In LF planning, the literature defined in Chapter 3.2.1 serves as a primary source of information. The term “Learning Methods” is introduced to identify the components of learning formats, enabling them to be planned during the training structure.

For instance, when planning a seminar, a variety of methods can be employed. These methods encompass presentations, maps, animations, videos, 3D models, case studies, discussions, lectures, group work, storytelling, polling, quizzes, speed dating, and boolean questions. Additionally, various elements and tools can be integrated into the seminar, including projectors, flip charts, pinboards, audio cassettes, learning software, blackboards, digital whiteboards, bulletin boards, and more.

It is important to note that post-training methods, such as forums, email communication with presenters, and feedback platforms, are not included in this list.

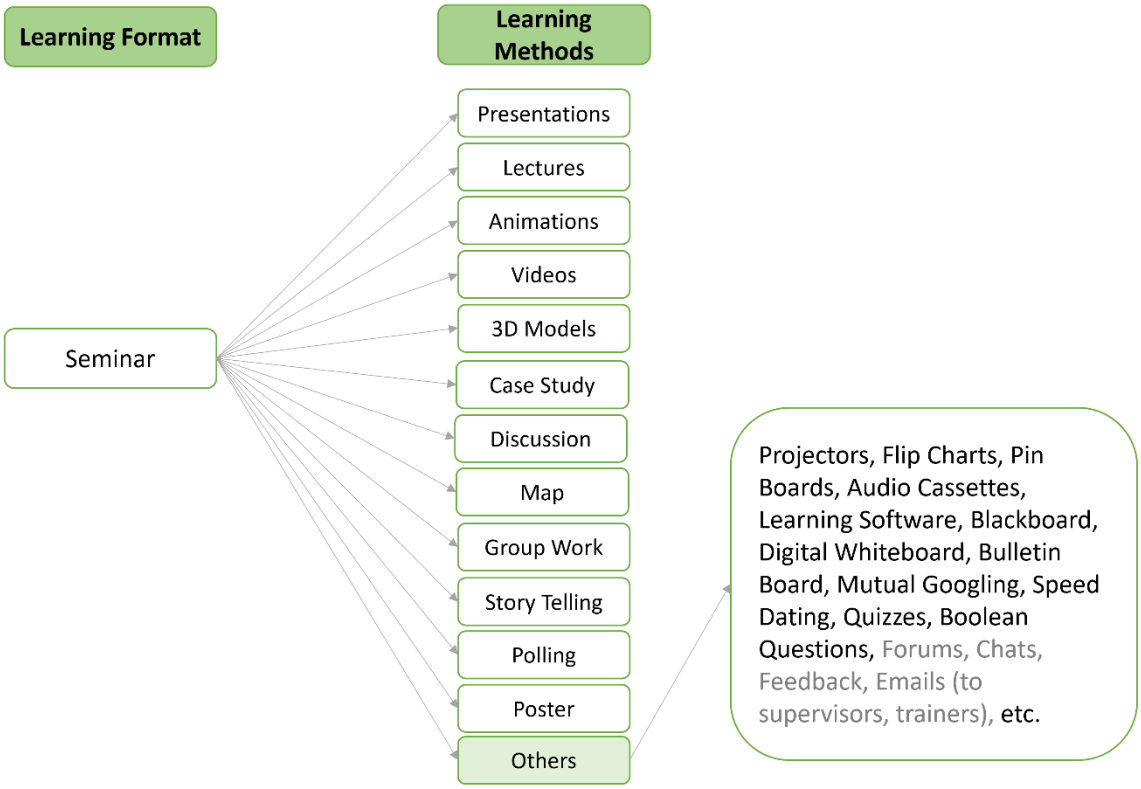


Figure 4-9: Learning methods for the LF Seminar

In Figure 4-9, the LF seminar planning is elaborated by highlighting various methods that can be used, including lectures, storytelling, discussions, group work, case studies, and many more.

In the "Other" category, various elements and tools are defined, offering a comprehensive list of options to be considered when planning or delivering a seminar. These include essential elements such as projectors, flip charts, pinboards, learning software, among others. These resources contribute to enhancing the overall seminar experience and effectiveness.

It should be noted that certain elements that are not primarily involved in content planning or during the delivery phase have been defined. Instead, they can be utilized later for further discussions and communication. However, it's important to clarify that these elements are not the central focus of this thesis; hence, they are indicated in grey colours. They serve as additional aspects that may come into play at later stages but are not the primary emphasis of our current discussion.

4.3.3.3 Recommendation of LF using archetypes

There are a total of seven qualification archetypes for SE mentioned in Chapter 3.1.7, defined by KÖENEMANN et al. These archetypes can be leveraged to define the learning format(s) based on company requirements and the level of SE introduction. To implement this, the idea is to create a mapping that shows which learning formats are better suited for specific archetypes, ultimately leading to recommendations for the company.

Mapping of Archetypes with the Learning Formats Mapping scale: ○ = Not Achievable ◐ = Partially Achievable ● = Achievable		Learning Formats									
		Seminar	Coaching	Mentoring	Game-Based Learning	Computer Based Learning	Conference	Web Based Learning	Webinars	Blended Learning	Self-Learning
Competency Acquisition	Archetypes										
Recognise	Basic Understanding	●	○	○	●	●	◐	●	◐	●	●
Understand	SE For Leaders	●	●	●	●	◐	◐	◐	◐	●	◐
	Continues Support	●	○	○	○	◐	◐	◐	●	●	●
Apply	Make Pilot Projects	●	●	○	◐	○	○	○	◐	●	○
	Need-Based Project-Oriented Training	◐	●	●	○	○	○	◐	◐	●	○
Mastery	Train The Trainer	○	●	●	○	○	●	○	○	◐	○

Table 4.9: Mapping of qualification archetypes to the identified LFs

The table consists of three matrices: “Not Achievable,” “Partially Achievable,” and “Achievable.” Once the qualification archetypes are identified during the requirement process, suitable LF recommendations can be made to individuals or organizations aiming to enhance the SE skills of their employees.

The table answers the question: “Which LFs are best suited for the identified archetype?” The identification of archetypes occurs in the requirement phase.

4.3.3.4 Recommendation of LFs based on the identified SE competencies

In the initial phase of the process method, the focus lies on pinpointing company-specific SE competencies. This step is crucial as it directly aligns with the unique requirements and objectives of the company.

The three-step process, outlined in Chapter 4.2.3, aims to establish the connection between the 16 SE competencies and the 10 finalized learning formats. The outcome of this mapping has been presented in Chapter 4.2.3.2.

This mapping serves as a valuable tool to suggest learning formats based on the specific competency requirements for the SE qualifications.

4.3.4 Introduction, execution, and evaluation

Figure 4-8 illustrates the fourth milestone, “Introduction and Execution”. In this phase, the objective is to train the trainees by executing a training program. This involves thorough planning of the training duration and setting predefined dates. Additionally, resource planning is a critical aspect, encompassing considerations such as trainer availability, especially during periods of high demand.

The last milestone involves evaluating the training, employing the 4-level KIRKPATRICK Model [Kir94]. This model offers a structured approach to assess qualification measures and estimate the success of the training program.

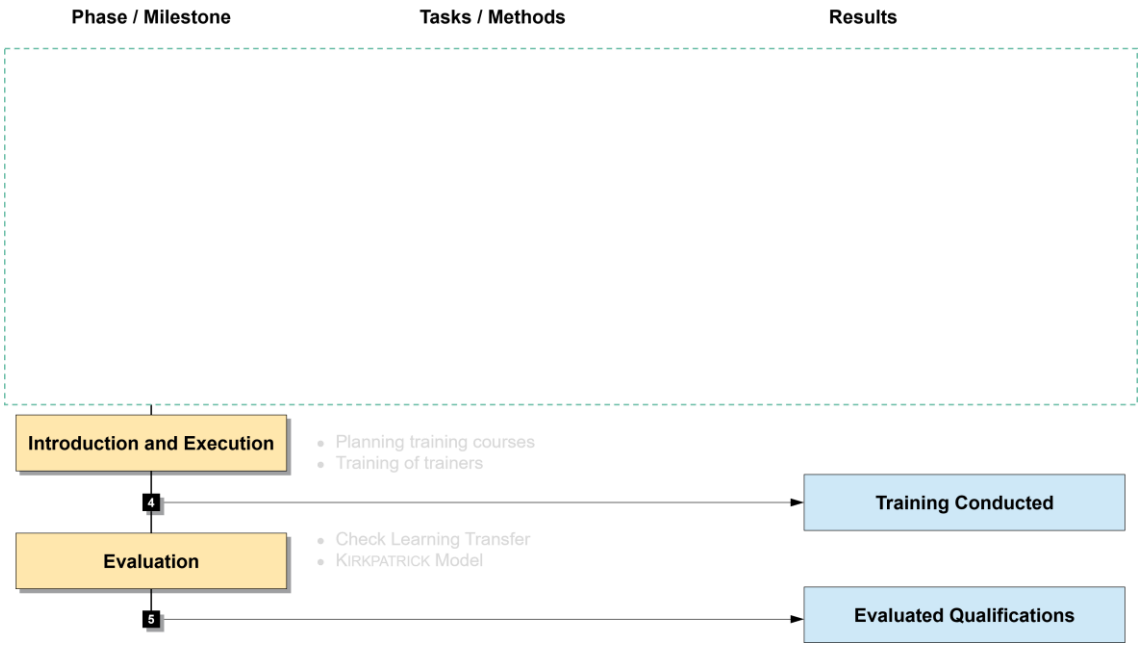


Figure 4-10: “Fourth” and “Fifth” phases of the process method

The tasks for these two phases are not identified as they fall outside the scope of this thesis. However, it would be exciting to look into executing the planned training using the methods defined in the first three phases and evaluate the training.

4.3.5 Evaluation of process methods

Initially defined by KÖENEMANN et al., the qualification process methods have undergone enhancements by incorporating additional tasks/methods in the first three phases and respective results, as discussed above and mentioned in Figure 4-11. These supplementary tasks play a crucial role in further structuring and effectively implementing qualifications in systems engineering. The modifications aim to refine the process, ensuring a broader and streamlined approach to systems engineering qualification.

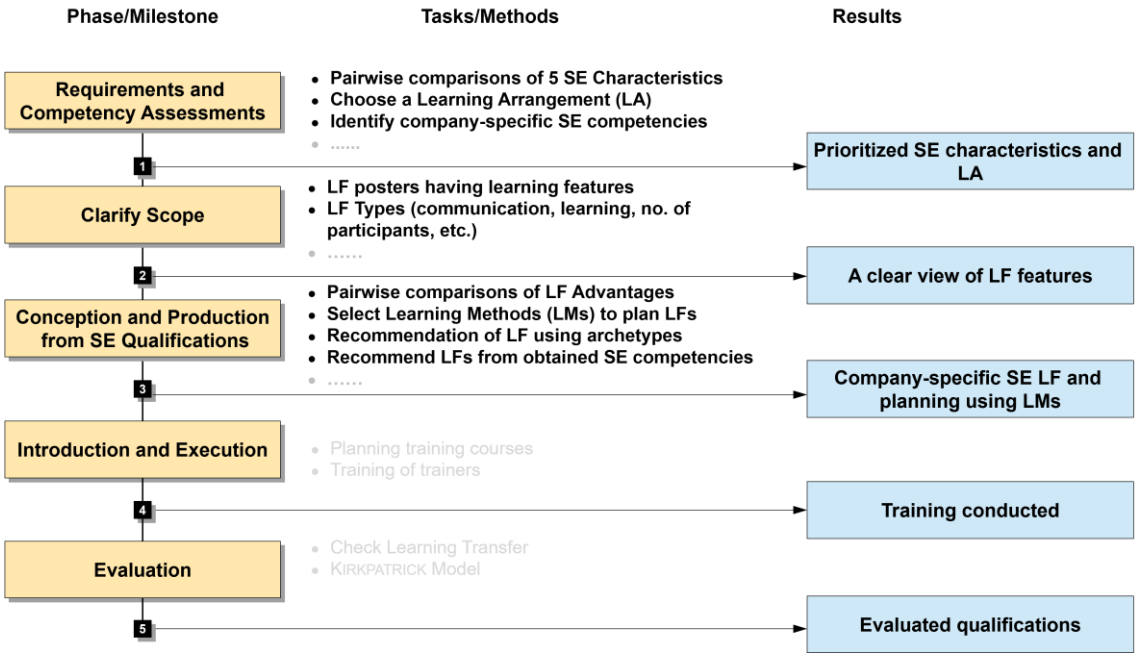


Figure 4-11: Adapted process methods for SE qualification defined by KÖENEMANN et al.

The process methods are not entirely validated as they require practical implementation. To validate the model, industry experts and companies need to actively engage in using this process. Additionally, participants are essential, as they represent the end-users of the training. Executing such a comprehensive plan could be time-consuming and might demand significant resources. Relying solely on expert validation may not suffice, emphasizing the importance of real-world application and participant feedback to ensure the effectiveness of the process.

5 Validation

Ensuring the validity and reliability of the obtained results is a critical aspect of the thesis, and various measures have been implemented to validate the findings. The research methodology includes systematic literature reviews and expert validation to enhance the robustness of the results.

According to GOLDBERG et al., seeking validation from experts is an integral part of a thesis's research methodology. It entails gathering insights from subject matter experts within the relevant field to verify the precision and dependability of the results. These experts assess the research design, methodology, and result interpretation, offering constructive feedback to enhance the overall quality of the research. This rigorous validation process not only strengthens the credibility of the findings but also guarantees their validity and reliability [GCV22].

5.1 Validation of posters and SE qualification characteristics

Figure 5-1 illustrates the comprehensive validation process for SE qualification characteristics and learning format posters. This detailed validation procedure is a two-step approach, initiating with the initial design and progressing to a second round of validation. The second validation involves a thorough review, incorporating feedback from industry experts. These experts bring experience and insights to ensure the robustness, accuracy, and applicability of the qualification characteristics and learning format posters.

The subsequent subchapters detail the specific steps undertaken during this rigorous review process, underscoring the quality and reliability in the validation of research outcomes.

Both the validation of SE qualification characteristics and the learning formats go hand in hand; therefore, they are defined under a single chapter. However, the validation process is split into multiple following subchapters.

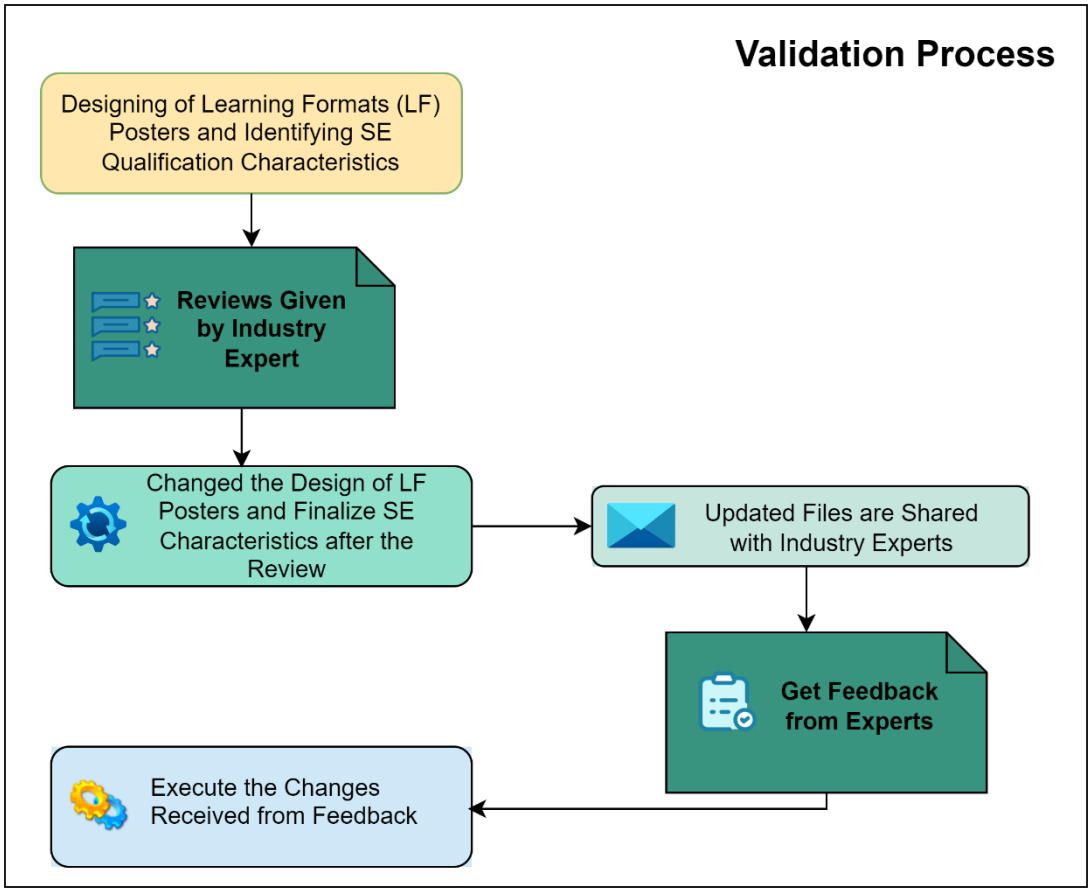


Figure 5-1: Validation process of posters of LFs and SE qualification characteristics

5.1.1 Designing of LFs and identification of SE characteristics

The posters are crafted for the identified learning formats, drawing insights from the literature discussed in Chapter 3.2.1. The initial design template is illustrated in Figure 5-2, encompassing the primary features of the posters. A total of nine sections are recommended in the poster of an LF.

Regarding the SE qualification characteristics, the initial findings highlight five key attributes: commitment, mindset, faithfulness, trustworthiness, and self-learning. These characteristics are presented in the first draft, which is open to review. Detailed explanations of these characteristics can be found in Chapter 4.2.1.1.

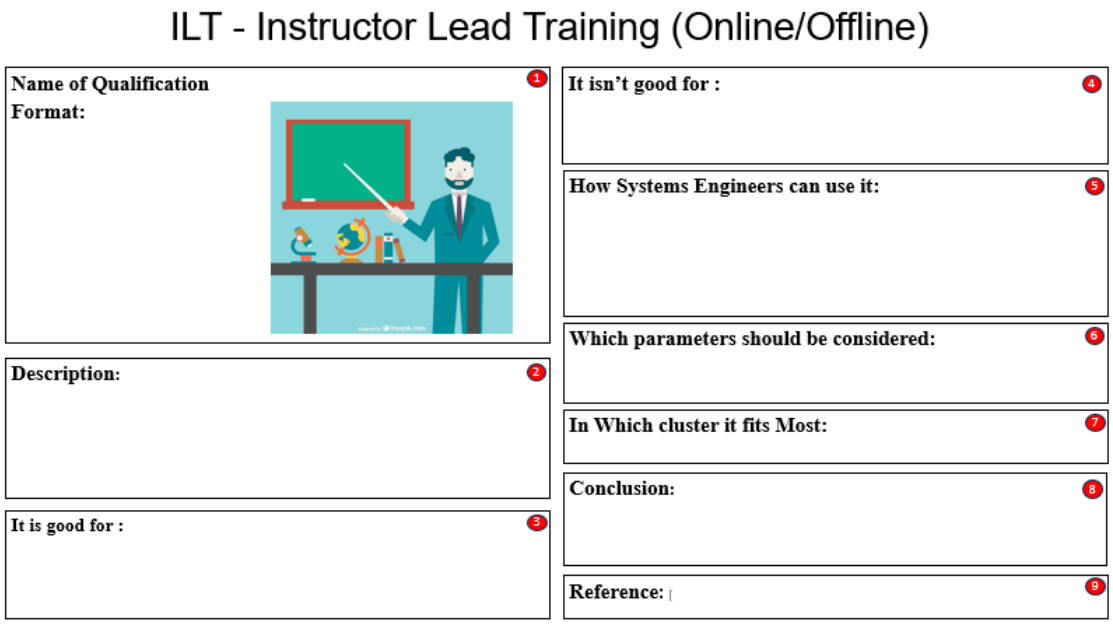


Figure 5-2: Poster skeleton for LF Instructor Lead Training

5.1.2 First Review Given by Expert

Once the LF posters were presented to the expert, some changes and additions were suggested based on the reviews, including:

- The absence of "Efforts" needed for content planning and content updating.
- Another recommendation is to include "Qualification Archetypes" with each poster.
- The observation that "Competency Acquisition" is not defined within the posters.
- The reviews also include the overview of the poster's "Evaluation" section.

Apart from the design changes, some additional remarks were also provided. These include adding the advantages and disadvantages of each format in a single place, using more visually appealing icons for each benefit and weakness, and employing self-explanatory names for them.

Regarding the SE qualification characteristics, the characteristics of faithfulness, trustworthiness, and self-learning were removed, as they were related to the content of the LF rather than the LF itself. Three other features that were suggested are:

- Transdisciplinary
- Holism
- Stakeholder-centricity

5.1.3 Changes After First Reviews

Once the first expert review was completed, the next step was to implement those reviews, further finalize, and explain the newly identified characteristics. Figure 5-3 shows the updated posters for the LFs, now with eleven sections, making them more informative and incorporating other aspects defined in the reviews.

The "Five" SE characteristics are also finalized and explained according to the feedback received. These qualification characteristics are further explained in Chapter 4.2.1.2 in detail.

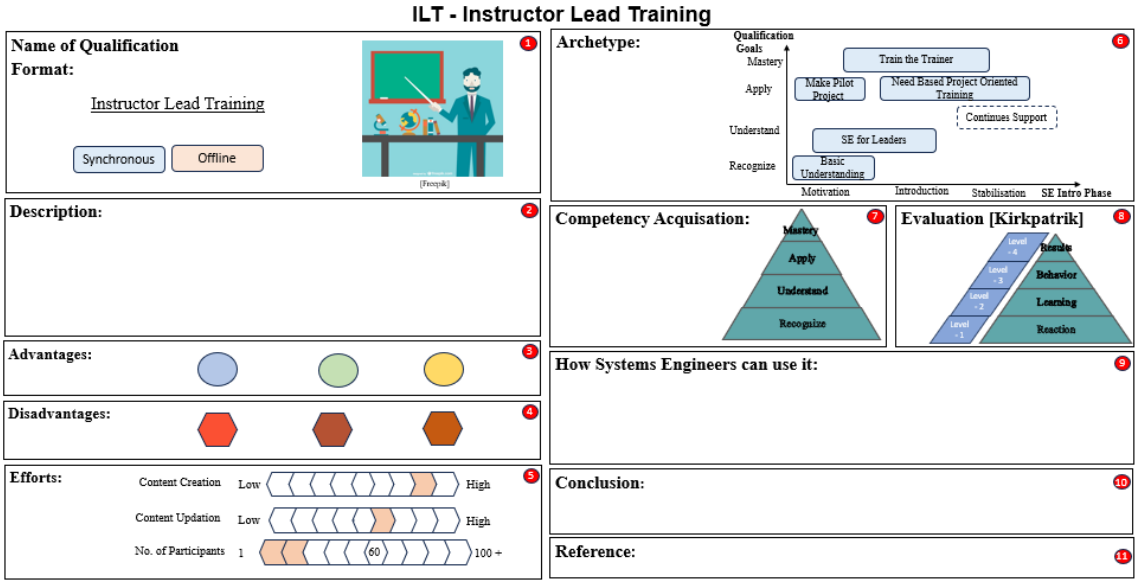


Figure 5-3: Poster skeleton for LF Instructor Lead Training after first expert review

5.1.4 Second Feedback from the Industry Expert

After incorporating changes received during the first feedback, the posters were shared with the qualification characteristics in a PDF for the second expert review. The section "Evaluation" was removed after discussion, as it was deemed more useful at the end of training rather than defining it for individual learning format. The updated file consists of all the advantages, disadvantages, and characteristics at the beginning of the file, and in the subsequent pages, learning formats are shown.

The second review included the following suggestions:

- Presenting the poster characteristics in tabular format in a single place instead of splitting them into different sections.
- Suggest changing the name from "Qualification Format" to "Learning Format," which was later synchronized with the entire thesis work.
- Minor changes related to the description of advantages and disadvantages were also suggested.
- It was proposed to give less preference to web-based training as it is quite outdated in the industry's learning formats and to introduce "AR/VR Based Learning" either as a format or a method.

These reviews played a crucial role in enriching and enhancing the effectiveness of the poster features for training.

5.1.5 Updated Posters of LFs After Review

After receiving the reviews, the posters were updated, as seen in Figure 5-4. LF characteristics were added to the posters, along with new metrics in the "Effort" section (as efforts per training). All the identified learning formats posters are defined in Appendix A-2. According to the reviews, the changes were also made in the advantages and disadvantages of LF.

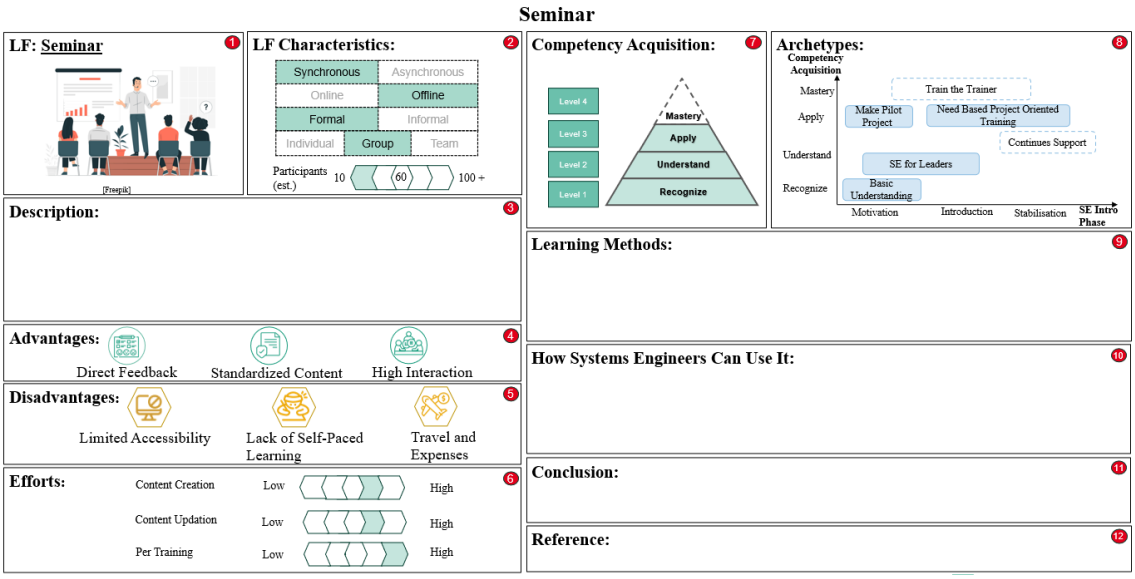


Figure 5-4: Poster skeleton for LF Seminar formally known as Instructor Lead Training after first expert review

6 Conclusion and future work

In this master's thesis, the primary objective is to identify suitable learning formats for systems engineers. This goal is divided into three distinct fields of action, each further subdivided to address specific requirements. Below, we define the three fields of action, along with the implemented solutions and the literature gaps associated with each of them:

The **first field of action** involves identifying and finalizing learning formats found in various literature sources. To achieve this, an extensive survey of relevant literature was conducted. The purpose of this survey was to extract the features of LFs since these features were not consolidated within a single source. Additionally, it was noted that many references lacked adequate coverage of systems engineering aspects.

The finalization of methods established well-defined advantages and disadvantages for each learning format. The formalization of these formats was accomplished through the designing of academic posters. These posters not only presented a concise introduction to each format but also delved into various aspects. These included indications of where a particular format could be applied effectively and areas where it might not be as helpful. Furthermore, the posters provided insights into the effort required for designing and presenting each format.

In the process, considerations were also made regarding the levels of SE competencies as defined by KÖENEMANN et al. [KWA+22, p.5]. These competencies, along with the SE archetypes, played a crucial role in the poster representations. The result of this work was the definition of learning methods in the form of posters for LF planning, offering guidance on how each format could be leveraged within the realm of systems engineering.

The finalized LFs are then grouped or clustered based on their characteristics, which are derived from various literature sources as defined in Chapter 3.2.1. The five identified characteristics include "Mode of Delivery," "Communication Type," "Collaboration Type," "Number of Participants," and "Learning Types." For each category, the LF characteristics are presented as a table, aiding in the selection of LFs based on specific requirements.

The **second field of action** involved identifying SE-related characteristics and leveraging them within the defined LFs. While the literature, particularly that defined by MUNDT [MWA+23] and the "INCOSE SE Handbook," played significant roles, they did not account for the aspects of LFs or SE characteristics.

As a result, five characteristics were defined under the guidance of SE experts. Subsequently, for SE characteristics, a LF matrix was established. This matrix serves to identify which LFs or combinations of LFs would be most effective in helping SE practitioners achieve these characteristics.

To provide a formalized result, an average of the scores for each LF across the five characteristics was calculated. This helps determine the relative importance of each LF. The resulting matrix offers valuable insights into the relationship between SE characteristics and the defined LFs, which can be further utilized in the later thesis requirements.

This brings us to the **third field of action**, which primarily concerns the methods for developing learning arrangements. Although. KÖENEMANN et al. [KSS+23, p.18] offer some insights into the planning process, their scope is limited to a few methods, and they do not consider the full range of SE characteristics.

The first requirement involves the planning of LFs. To fulfill this requirement, we drew from the literature defined in Chapter 3.2.1, and subsequently, multiple methods were defined for each learning format.

Another requirement was establishing the relationship between SE competencies and the identified SE characteristics. To address this need, we sought expert input after formally defining these relationships in matrix form. The resulting matrices provide clear explanations regarding which SE characteristics are most suitable for each SE competency.

We further combined these results with the outcomes of the second field of action, the mapping of LFs to SE characteristics. This combined result (matrix multiplication of A and B) offers insights into which LFs are most suitable for each SE competency. The matrix also provides valuable information about the overall importance of an LF in terms of competency development.

Another method we employed for planning involves SE archetypes, taking into account company maturity and expected competency levels. These archetypes help suggest the suitability of identified LFs for each archetype. The results derived from these seven archetypes provide extensive information for planning LFs under various conditions.

6.1 Future work

In the context of advancing qualification in systems engineering, several potential areas for exploration have emerged:

1) **Role-based learning formats**: While the existing learning formats have been tailored to the 16 SE competencies, considering the specific roles within the field of systems engineering could yield valuable insights. Investigating the relationship between role-based competencies and the corresponding LFs offers a narrowed design of learning programs that precisely match role-specific requirements. It opens the door to developing customized training paths that align closely with specific career trajectories within the systems engineering domain.

2) **Content planning of the LF**: The focus of this research has primarily centred on the structure and suitability of learning formats rather than the content within those formats. A promising way for future investigation would be to look into the content planning of identified learning formats, aligning them more precisely with the specific requirements and desired learning outcomes. This direction allows for a deeper exploration of how the content can be tailored to enhance the effectiveness and relevance of learning programs. Such an approach could lead to more targeted and content-specific training that meets the evolving demands of the field.

3) **Validation of the process methods**: The process methods discussed in Chapter 4.3 open up an exciting direction for future research. Currently, the model needs more validation, and a comprehensive approach involving collaboration with companies, instructors, trainees, and additional resources is required. Implementing such a validation process is anticipated to be time-intensive. However, its potential benefits for systems engineers and trainees are substantial. Validating the process methods could shed light on its effectiveness in streamlining the planning of training content, ultimately assisting trainees by suggesting tailored training programs aligned with company requirements. This exploration would contribute valuable insights into the practical implications and advantages of the proposed model in real-world scenarios.

4) **Qualification assessment**: Another question to explore involves evaluating the proficiency of systems engineers across various levels of BLOOMS qualification acquisition. For instance, if a system engineer aims to begin at the "Apply" level (as defined in Chapter 3.1.5), it raises questions about their knowledge of the foundational levels of SE competencies such as "Recognize" and "Understand." Furthermore, delving into the criteria necessary to distinguish between these levels in the context of assessments would add depth to this inquiry. Digging deeper into the questioning, identifying the specific criteria that should distinctly mark the boundaries between these assessment levels becomes interesting. This increases our understanding and opens up pathways for a more comprehensive analysis.

References

[Van12] VANDEWALLE, D.: A Growth and Fixed Mindset Exposition of the Value of Conceptual Clarity. Industrial and Organizational Psychology, Vol. 5, Iss. 3, 2012, p. 301–305

[Lib20-ol] LIBRARY AND LEARNING SERVICE: Academic poster. Unter: https://libguides.staffs.ac.uk/ld.php?content_id=3111812, 18. April 2023

[DAR21] DUMITRESCU, R.; ALBERS, A.; R.EDS.: Advanced Systems Engineering - Engineering in Germany - The status quo in business and science, a contribution to Advanced Systems Engineering, 2021

[LH17] LONGMUß, J.; HÖHNE, B. P.: Agile Learning for Vocationally Trained Expert Workers. Expanding Workplace-based Learning One Sprint at a Time. Procedia Manufacturing, Vol. 9, 2017, p. 262–268

[TG14] THOMAS, V.; GARDNER, B.: Building an Information Security Awareness Program - Defending Against Social Engineering Hacks and Technical Threats, 2014

[Jos21] JOSHI P. L.: Change Management and Management of Mindset, Vol. 2, 2021

[MNB95] MULDER, M.; NIJHOF, W. J.; BRINKERHOFF, O.: Corporate Training For Effective Performance, 1995

[Loo01] LOOß M.: DDS-Types of learning? A pedagogic hypothesis put to the test, Vol. 2, 2001, p. 186–198

[Fre98] FREDERIC, V.: Denken, Lernen, Vergessen, 1998

[SHG18] SANDMEIER, A.; HANKE, U.; GUBLER, M.: Die Bedeutung der Gestaltung des Lernfelds und des Funktionsfelds für den subjektiven Erfolg betrieblicher Weiterbildung. Zeitschrift für Weiterbildungsforschung, Vol. 41, Iss. 1, 2018, p. 41–55

[PAS 1032-1] DIN Deutsches Institut für Normung e. V.: Aus- und Weiterbildung unter besonderer Berücksichtigung von e-Learning 1032-1:Februar 2004

[JKS22] JACOBS, J. C.; KAGERMANN, ROEHL, H.; SPATH, D.: Dynamic Skills Management: Identifying Skills Requirements early, Devising Taylored Solutions (acatech DISCUSSION), 2022

[Kir94] KIRKPATRICK, D. L.: Evaluating Training Programs. The Four Levels. Berrett-Koehler Organizational Performance Series., 1994

[GCV22] GOLDBERG, A. S.; CHERNISH, N.; VAVILOVA, T. V.: Expert validation of the clinical laboratory service models' standardized descriptors. Manager Zdravoochranenia, Iss. 6, 2022, p. 12–20

[Zeu16] ZEUCH, M.: Handbook of Human Resources Management. Springer Berlin Heidelberg, Berlin, Heidelberg, 2016

[GKK+16] GUNDOGAN, B.; KOSHY, K.; KURAR, L.; WHITEHURST, K.: How to make an academic poster. Annals of Medicine and Surgery, Vol. 11, 2016, p. 69–71

[KWA+22] KOENEMANN, U.; WILKE, D.; ANACKER, H.; DUMITRESCU, R.: Identification of stakeholder-specific Systems Engineering competencies for industry, 2022

[BGD+18] BEASLEY, R.; GELOSH, D.; DON S.; HEISEY, M.; PRESLAND, I.; ZIPES, L.: INCOSE Systems Engineering Competency Framework, 2018

[INC23] INCOSE: INCOSE Systems Engineering Handbook. John Wiley & Sons, 5, 2023 - ISBN 978-1-119-81429-0

[Int15] INTERNATIONAL COUNCIL ON SYSTEMS ENGINEERING: INCOSE Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities. Wiley, 4, 2015 - ISBN 978-1-118-99940-0

[KSS+23] KOENEMANN, U.; SCHABBEHARD M.; SCHWEDE, J.; HILLMANN, V.; WORTMANN, A.: Laden zur Systems Engineering Qualifizierung: von der theorie in die Praxis,, Paderborn, 2023

[Lin22-ol] ANTHONY SANTA MARIA: Learning Format Types and When to Use Them. Unter: https://www.linkedin.com/business/talent/blog/learning-and-development/learning-format-types-and-when-to-use-them, 15. April 2023

[Pro21] PROHASKA, S.: Lernen im digitalen Wandel - Der E-Learning-Kompass für erfolgreiche Schulungskonzepte. Junfermann Verlag, Paderborn, 2021

[GE17] GRAF, N.; EDELKRAUT, F.: Mentoring. Springer Fachmedien Wiesbaden, Wiesbaden, 2017

[Ied22-ol] MUNTASIR, M.: Methods of Training. Unter: https://www.iedunote.com/methods-of-training, 18. April 2023

[MJM+23] MOHTAR, S.; JOMHARI, N.; MUSTAFA, M. B.; YUSOFF, Z. M.: Mobile learning: research context, methodologies and future works towards middle-aged adults - a systematic literature review. Multimedia tools and applications, Vol. 82, Iss. 7, 2023, p. 11117–11143

[Kau10] KAUFFELD, S.: Nachhaltige Weiterbildung - Betriebliche Seminare und Trainings entwickeln, Erfolge messen, Transfer sichern. Springer, Berlin, Heidelberg, 2010

[Ram20] RAMÍK, J.: Pairwise Comparison Matrices in Decision-Making. In: Ramík, J. (Ed.): Pairwise Comparisons Method, 2020, Springer International Publishing, Cham

[MWA+23] MUNDT, G.; WILKE, D.; ANACKER, H.; DUMITRESCU, R.: Principles for the effective application of Systems Engineering: A systematic literature review and application use case, 2023

[KFL+01] KLIEME, E.; FUNKE, J.; LEUTNER, D.; REIMANN, P.; WIRTH, J.: Problem-solving as transdisciplinary competence - Conception and first results of a study on school achievement - Zeitschrift für Padagogik, Vol. 47, Iss. 2, 2001, p. 179–200

[PLN] PYLVÄS, L.; LI, J.; NOKELAINEN, P.: Professional Growth and Workplace Learning. In: Harteis, C.; Gijbels, D.; Kyndt, E. (Eds.): Research Approaches on Workplace Learning, 2022, Springer International Publishing, Cham

[Sch23] SCHRADER, C.: Serious Games and Game-Based Learning, 2023, p. 1255–1268

[AD23] ABDULSADA, M.; DARWEESH, H.: Speech act analysis of academic webinars, 2023

[HWF+19] HABERFELLNER, R.; WECK, O. de; FRICKE, E.; VÖSSNER, S.: Systems Engineering - Fundamentals and Applications. Springer International Publishing, Cham, 2019

[Stü21] STÜTZEL BENNO: Systems Engineering in Deutschland - Die deutsche Unternehmenslandschaft im Vergleich, 2021, p. 15

[BEF+56] BLOOM, B. S.; ENGELHART, M. D.; FURST, E. J.; HILL, W. H.; KRATHWOHL, D. R.: Taxonomy of Educational Objectives - The Classification of Educational Goals, Handbook I: Cognitive Domain. Longman Group, 1, 1956

[MGV+16] MOICA, S.; GHERENDI, A.; VERES, C.; MOICA, T.: The Integration of the Blended Learning Concept into Employee Training as a Factor in Shifting Mentalities towards the Industry 4.0 Approach. In: Stanišić, M.; Veinović, M.; Stanišić Stojić, S.; Šarac, M.; Adamović, S.; Jevremović, A.; Mihajlović, A.; Lazović, V.; Milenković, A.; Obradović, P.; Knežević, M.; Petrović, A. (Eds.): Proceedings of the International Scientific Conference - Sinteza 2016. Sinteza 2016, 4/22/2016 - 4/22/2016, Belgrade, Serbia, Singidunum University, Belgrade, Serbia, 2016

[KKK+23] KABASAKAL, I.; KAYMAZ, Y.; KESKI, F.; ÇIÇEKLI, U., KOÇAK, A.; KOCAMAZ, M.; SOYUER, H.; DURAKBASA, N.: Towards Industry 5.0 - A Customized Web-Based Training Platform for Industry 4.0. Springer International Publishing, Cham, 2023 - ISBN 978-3-031-24456-8

[BFB+10] BLUME, B. D.; FORD, J. K.; BALDWIN, T. T.; HUANG, J. L.: Transfer of Training: A Meta-Analytic Review. Journal of Management, Vol. 36, Iss. 4, 2010, p. 1065–1105

[She96] SHEARD, S.: Twelve Systems Engineering Roles, 1996

[BG99] BOUD, D.; GARRICK, J.: Understanding learning at work. Routledge, London, 1999 - ISBN 9780415182287

[SFS19] SÁ, M. J.; FERREIRA, C. M.; SERPA, S.: Virtual and Face-To-Face Academic Conferences: Comparison and Potentials. Journal of Educational and Social Research, Vol. 9, Iss. 2, 2019, p. 35–47

A1 Identified LFs comparisons

Table to show the comparison of various learning formats identified from various literatures

Reference - 1 (Prohaska, Pro21)	Reference - 2 (Kauffeld, Kau10)	Reference - 3 (Valerie, TG14)	Reference - 4 (Mulder et al., MNW+95)	Reference -5 (Zeuch, Zeu16)	Specific References	Summary
Live Online Seminar/ Live Online Training	-	-	-	Online Seminar / e-Seminar	-	**Online Seminar**
Blended Learning	Blended Learning	Blended Learning	-	Blended Learning	Blended Learning - Moica et al., MGV+19	**Blended Learning**
-	-	-	-	-	Agile Learning - Longmuß et al., LH17	**Agile Learning**
Coaching	Coaching	-	Coaching	Coaching	-	**Coaching**
Computer Based Training	Computer Based Training	Computer Based Training	Computer Based Training	Computer Based Training	-	**Computer Based Training**
Webinar / Live Online Event / Video Conferences	Face to Face Online Training	-	-	-	Webinars - Abdulsada et al., AD23	**Webinar**
Games Based Learning/Gamification	Games Based Learning/Gamification	-	Training via Simulated Games	Games Based Learning	Game Based Learning - Schrader, Sch23	**Games Based Learning**
-	Mentoring	-	Mentoring	Mentoring	Mentoring - Graf et al, GE17	**Mentoring**
Seminar/ Classic Seminar	Seminar	Instructor Led Training / Face to Face Training	Seminar	Seminar	-	**Seminar**
Web Based Training	Web Based Training	Web Based Training	-	Web Based Training	-	**Web Based Training**
-	Web Conferences	-	-	Conferences	Conference - Maria et al. SFS19	**Conferences**

Table A-1: Table showing the finalize learning formats

A2 Advantages and disadvantages of LFs

Possible advantages and disadvantages of learning formats are defined in this appendix.

Possible Advantages of Learning Formats (LFs)

- **Direct Feedback**: Participants can interact with the trainer to discuss the topics and clear their doubts during the session.
- **Standardized Content**: The learning material presented by the instructor is generally standardized, measured, and tested. Such that participants get up-to-date knowledge.
- **High Interaction**: The interaction between the participants is high if group discussions or roleplay are added as a learning arrangement for the training. Participants get a different perspective on the same topic. Challenging tasks for groups can trigger group dynamics and processes that promote learning.
- **Accountability**: Trainer(s) hold individuals accountable for their actions and commitments. This accountability helps individuals stay focused, motivated, and on track toward their goals.
- **Personalized Guidance**: The Learning format provides one-on-one support and tailors their guidance to the individual's specific needs, goals, and challenges.
- **Self-Discovery**: The LF encourages self-reflection and self-discovery. Individuals gain a deeper understanding of their strengths, weaknesses, values, and beliefs, which can lead to personal growth and self-improvement.
- **Successor Training**: The LF aids in succession planning by identifying and preparing future leaders within the organization.
- **Personalized Content**: The LF offers personalized content delivery, adapting challenges and resources to individual learners for a more engaging and effective learning experience.
- **Measurable Outcomes**: The LF allow for the measurement of specific learning outcomes and performance improvements, enabling organizations to assess the effectiveness of their training programs.
- **Exposure To New Ideas**: The LF often showcase innovative ideas, projects, and technologies. Exposure to new concepts can inspire creativity and innovation in attendee's work or research.
- **Global Reach**: The LF can reach a global audience, transcending geographical boundaries and language barriers.
- **Allows Tracking and Assessment**: The LF often include tracking features that allow administrators to monitor learner's progress and performance, making it easier to assess the effectiveness of training programs.
- **Self-Paced Learning**: Learners can pause and return to courses as needed and learn at their own pace, promoting flexibility and autonomy in their learning journey.

Possible Disadvantages of Learning Formats (LFs) – 1/2

Limited Accessibility: The Learning Format (LF) is unsuitable for online learners since the program is face-to-face in-presence training.

Lack of Self-Paced Learning: The LF often follows a predetermined schedule with fixed topics and timelines. This structured approach may not be suitable for self-paced learners who prefer to study and absorb content at their own pace.

Travel and Expenses: Attendees often need to incur travel expenses, including transportation, accommodation, etc., to attend face-to-face format. This can be costly and may deter some from participating.

Limited Instructors: Finding a dedicated trainer with the appropriate qualifications that match company needs can often be a challenging task.

Gradual Results: The LF is a process that takes time and effort. It may not provide immediate solutions to complex problems, and individuals may need to be patient and persistent in their efforts.

Time Intensive: The LF often requires a significant time commitment, both for the trainer(s) and the trainee(s), which may not be feasible for everyone.

Limited Knowledge Transfer: The LF may prioritize engagement over in-depth content coverage. While they are effective for experiential learning, they may not provide the same level of depth as traditional educational materials.

High Initial Development Cost: Developing the LF can be expensive and time-consuming. Developing engaging and effective content requires highly skilled teams.

Technical Requirements: By using the LF, learning may require specific hardware or software, such as gaming consoles or powerful computers. Access to these technologies may be limited for some learners.

Time-Consuming: The LF often span several days, requiring attendees to dedicate a significant amount of time away from their regular work or responsibilities.

Possible Disadvantages of Learning Formats (LFs) – 2/2

Very Low Interaction: The interaction between the instructors and participants is very low in this learning format. Some asynchronous methods (like emails, forums, etc.) can be used in communication.

Low Engagement: Not all learning programs are designed to be engaging, and some may lack interactive or multimedia elements, potentially leading to reduced learner engagement.

Limited Instructor guidance: Some LFs may lack the immediate guidance and support of an instructor, making it challenging for learners who require personalized assistance or clarification on complex topics.

Technical Issues: Technical problems, such as software glitches, internet connectivity issues, or hardware malfunctions, can disrupt the learning process.

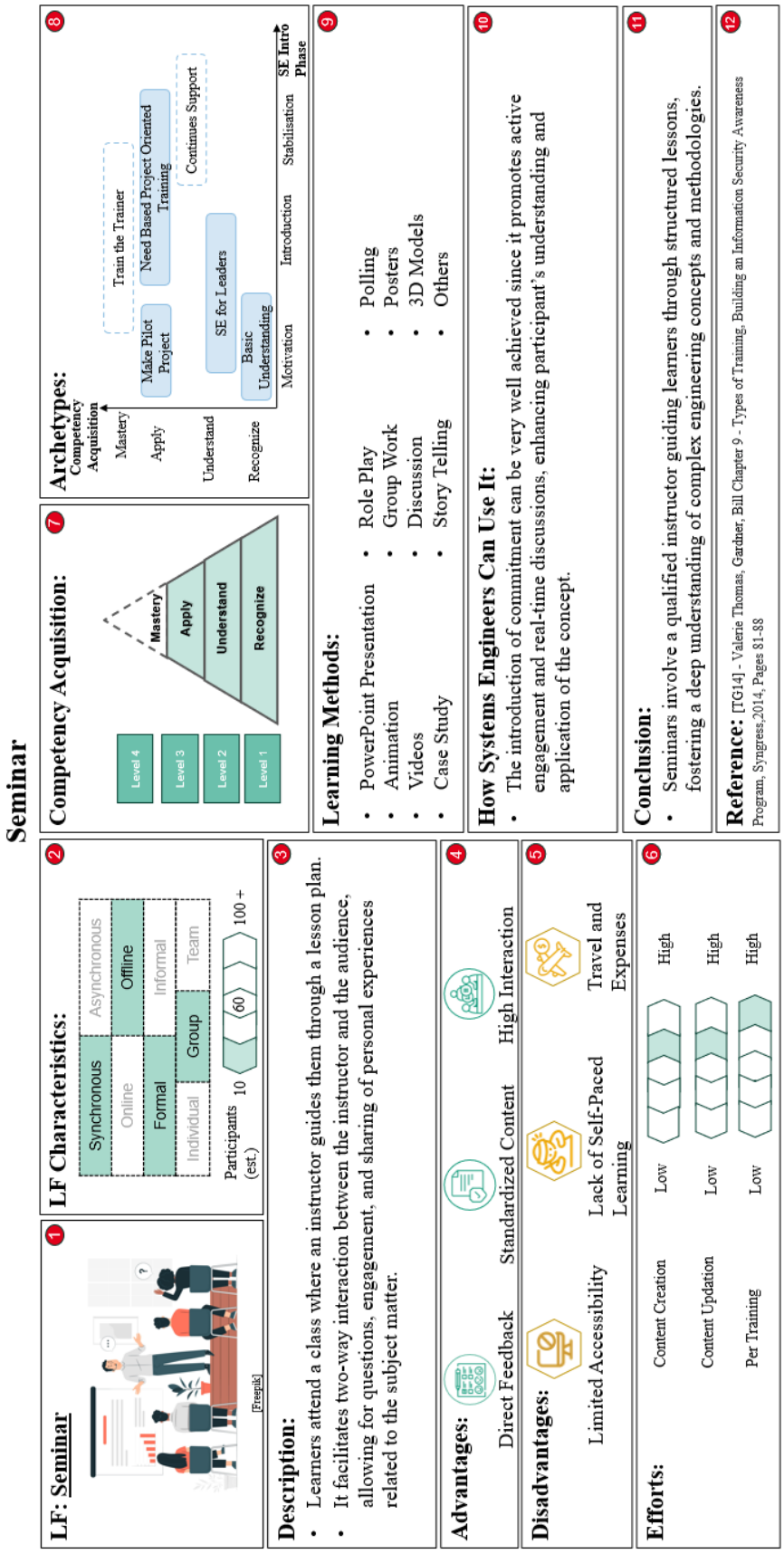
Course Planning Hurdles: There is a need to balance online and in-person components effectively, ensuring seamless integration of technology and addressing the diverse needs of learners, all while maintaining course quality and engagement.

Integration Challenges: The difficulties encountered when seamlessly incorporating course materials and activities into the existing learning management system or tools. These challenges can include technical issues and compatibility problems, among others.

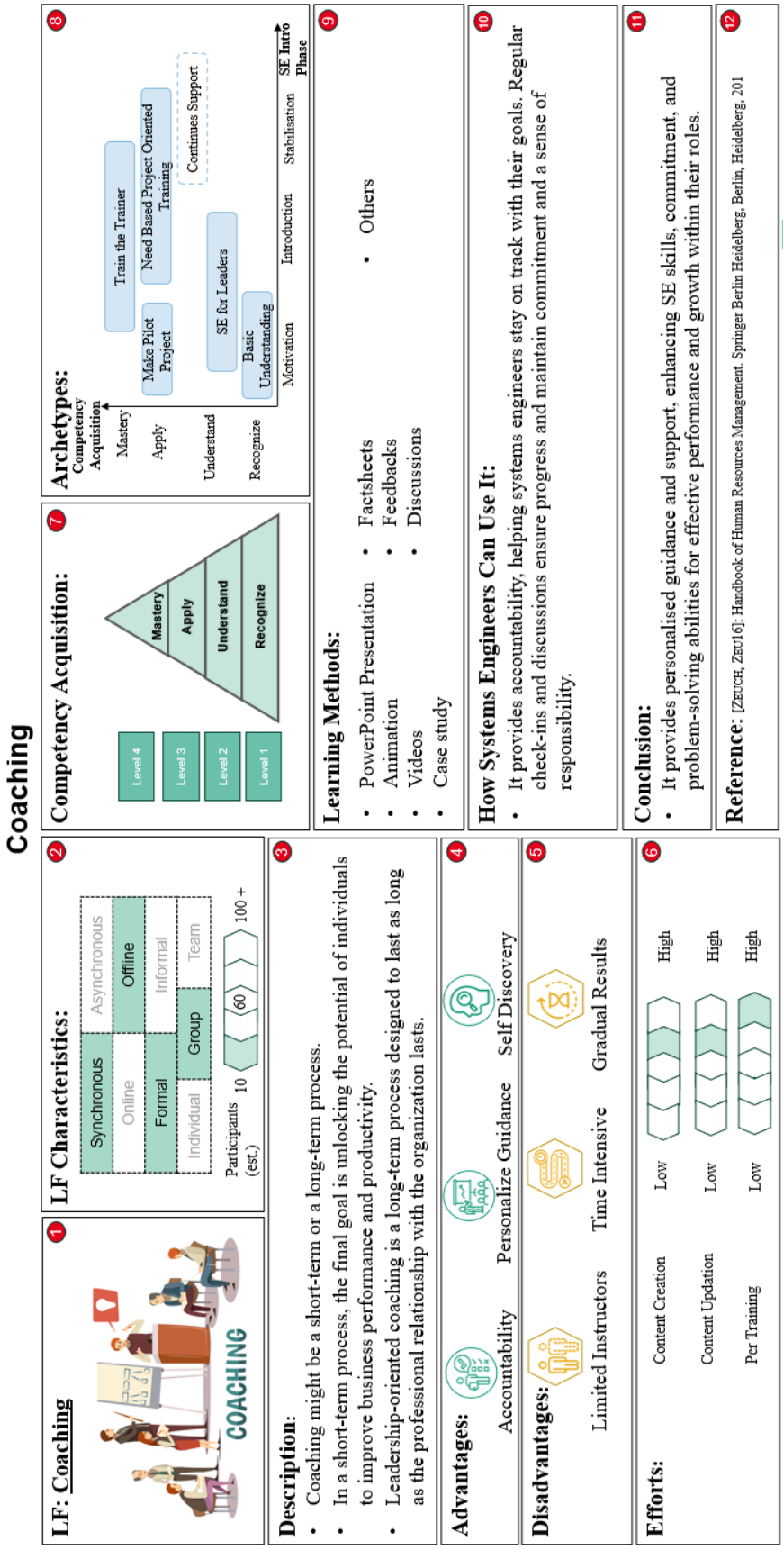
Time Management Challenges: Learners may encounter ineffectively allocating and managing their time between online and in-person components of the course. These challenges include balancing work, study, and personal commitments, adhering to deadlines, and maintaining a consistent learning schedule.

Medium Interaction: The QF exhibit a relatively high degree of engagement among the participants themselves. However, the interaction between the presenters and participants remains notably limited.

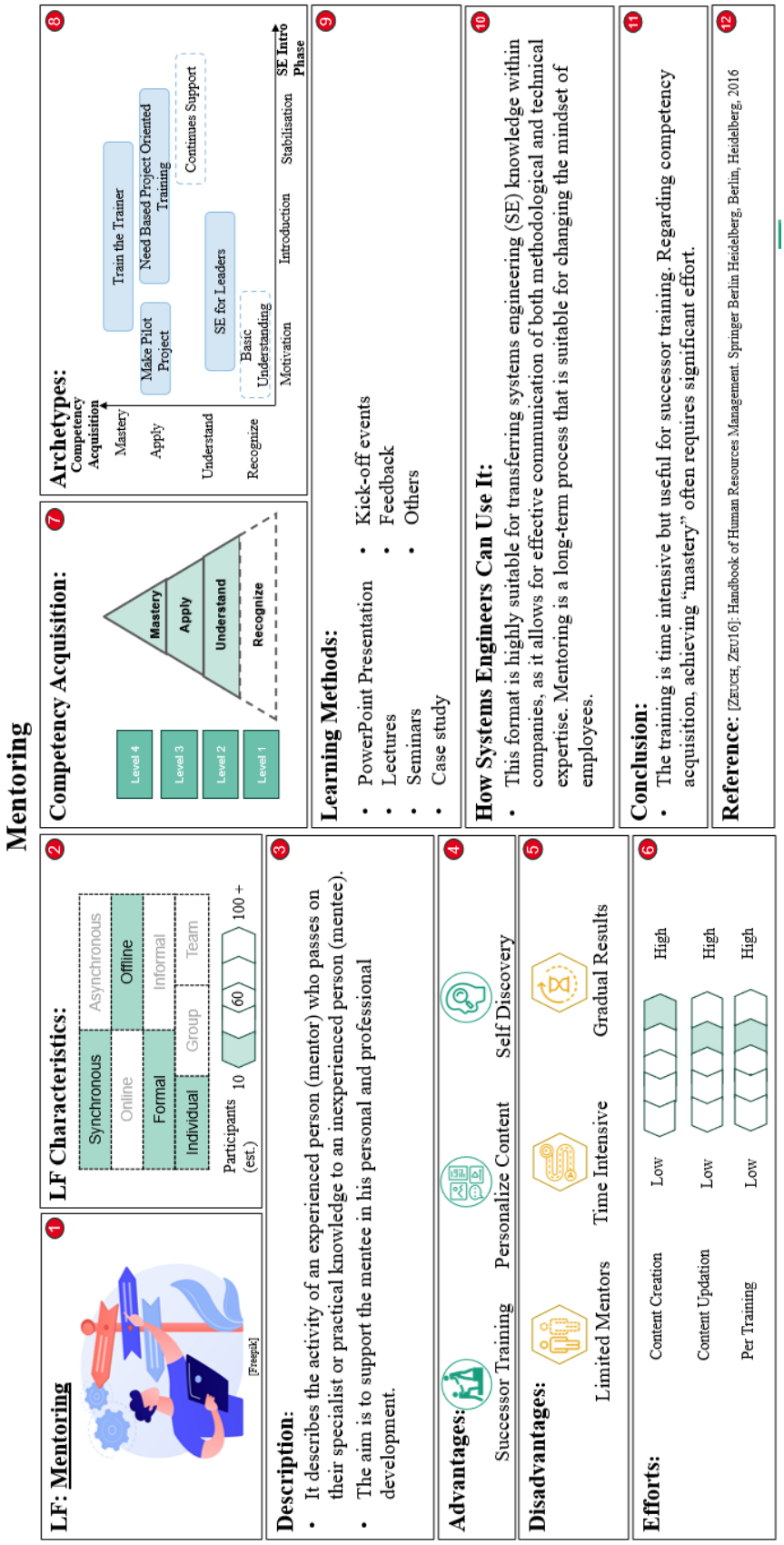
A3 Posters of identified LFs: Seminar



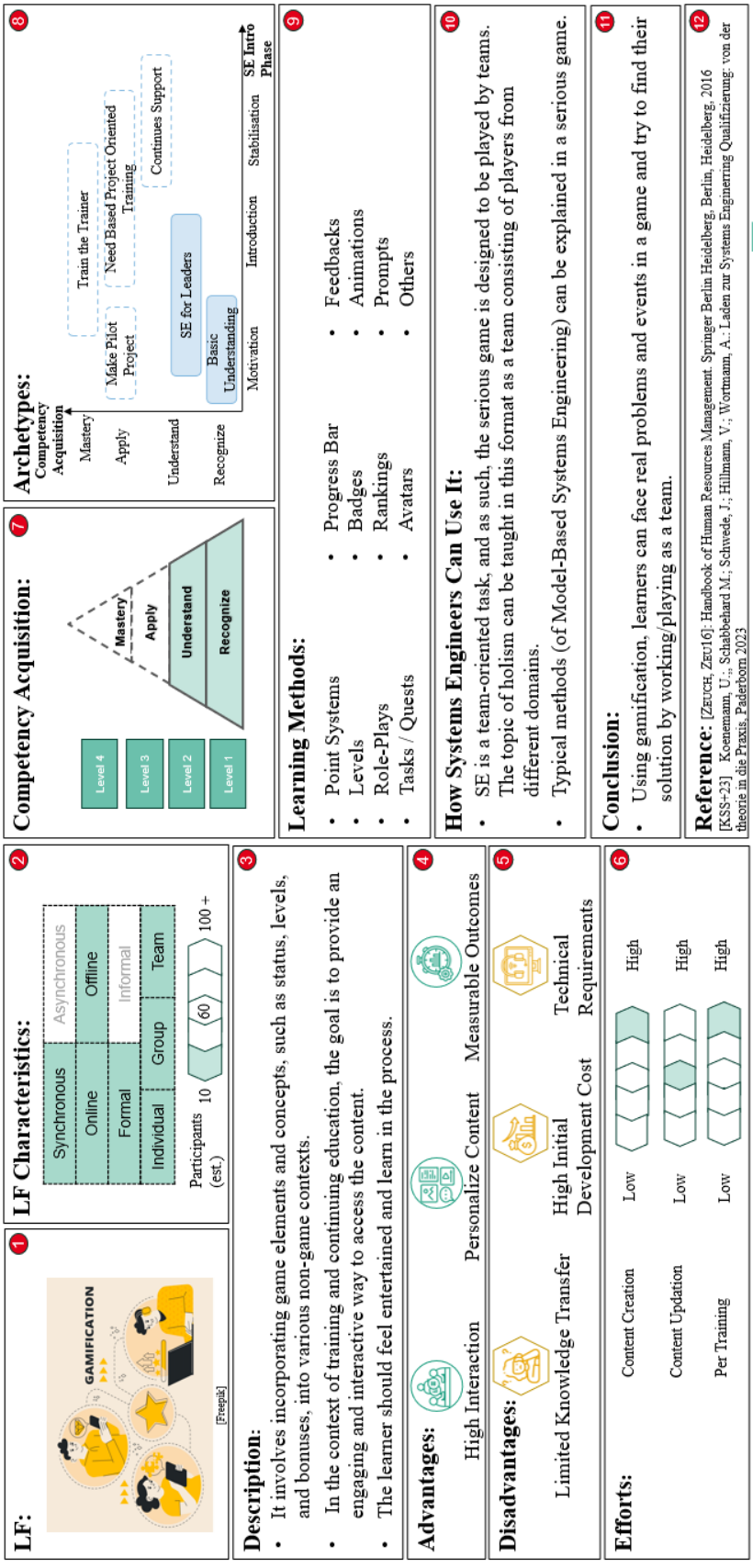
Learning Format: Coaching



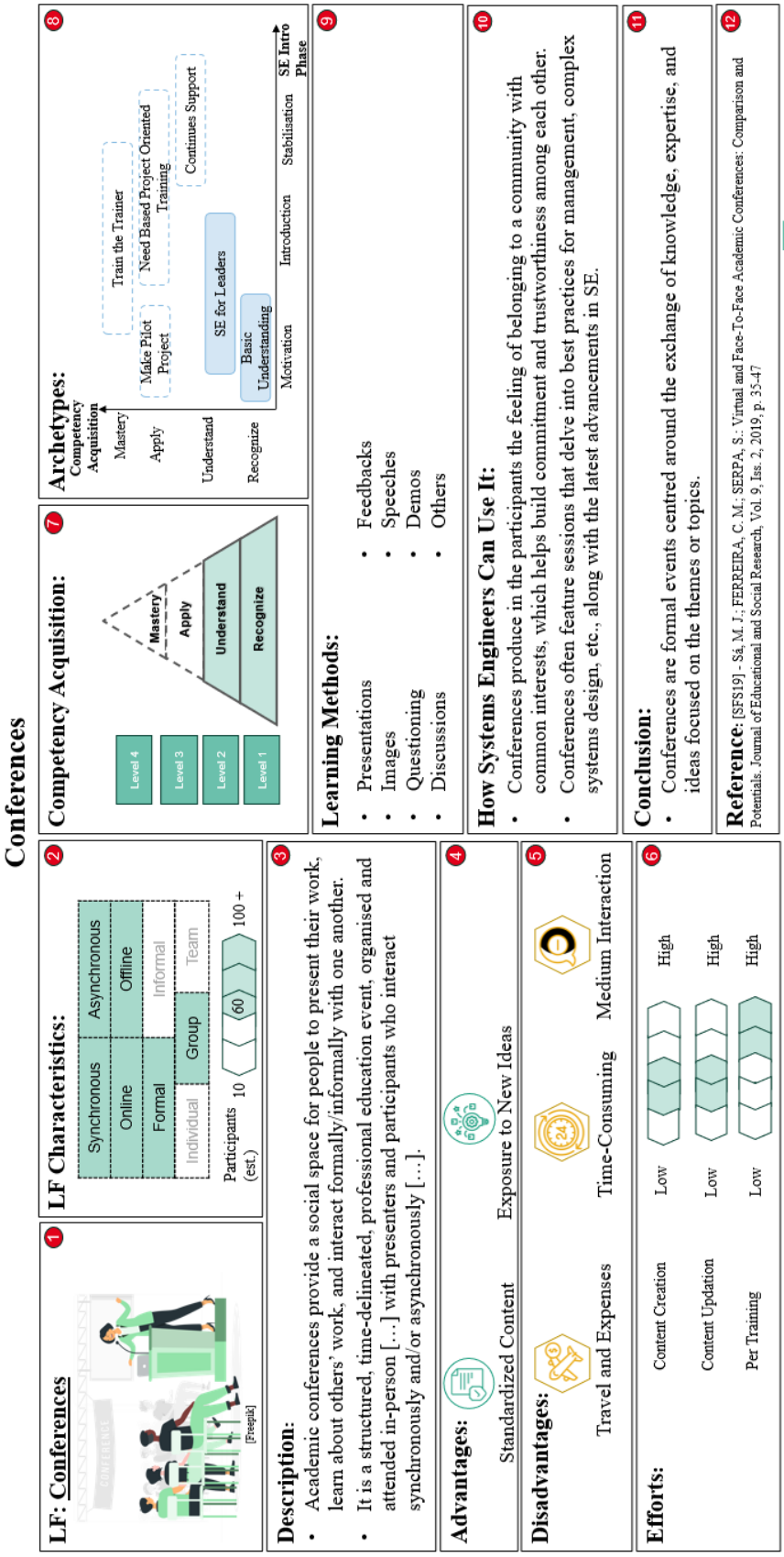
Learning Format: Mentoring



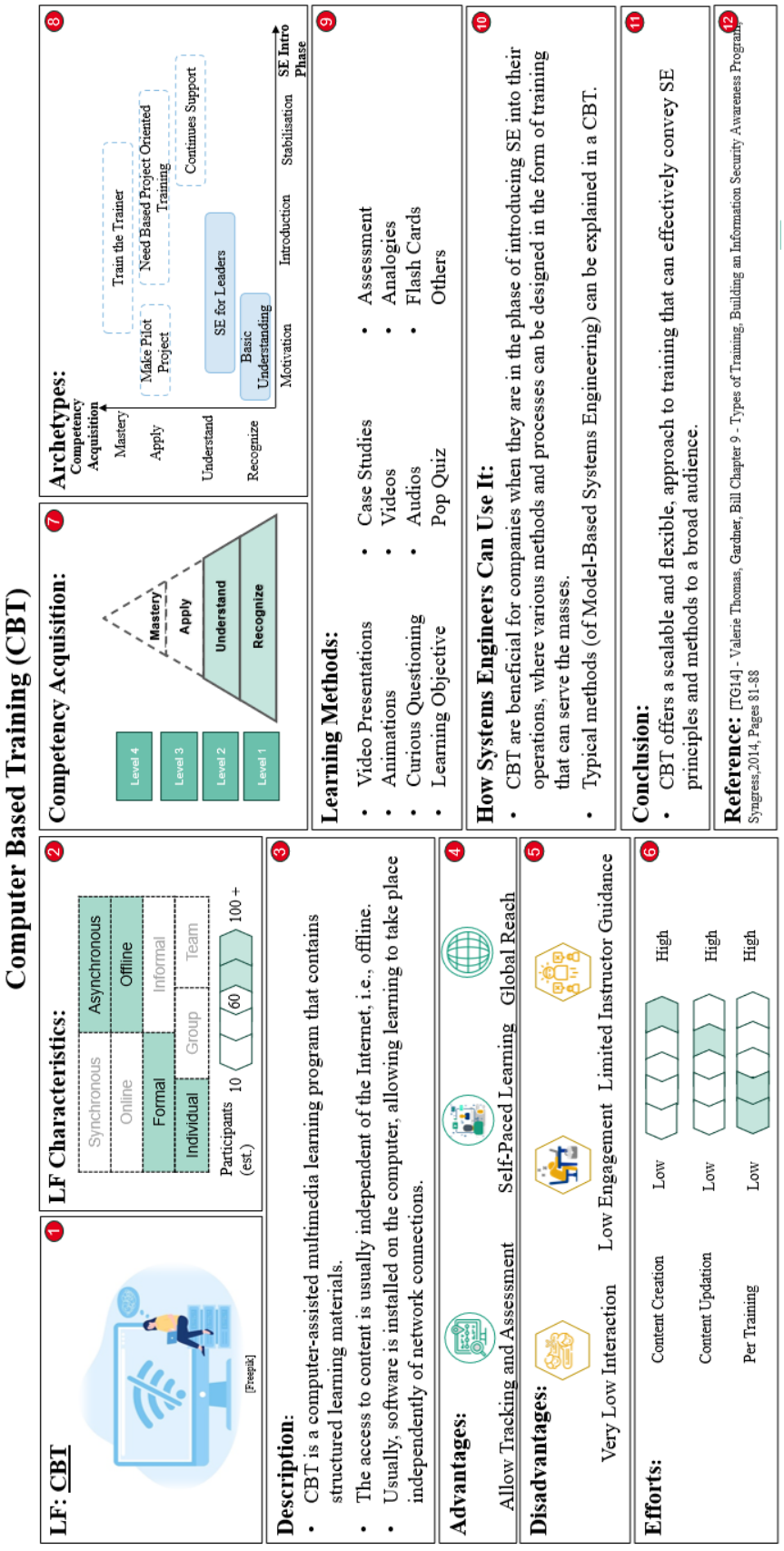
Learning Format: Game-Based Learning



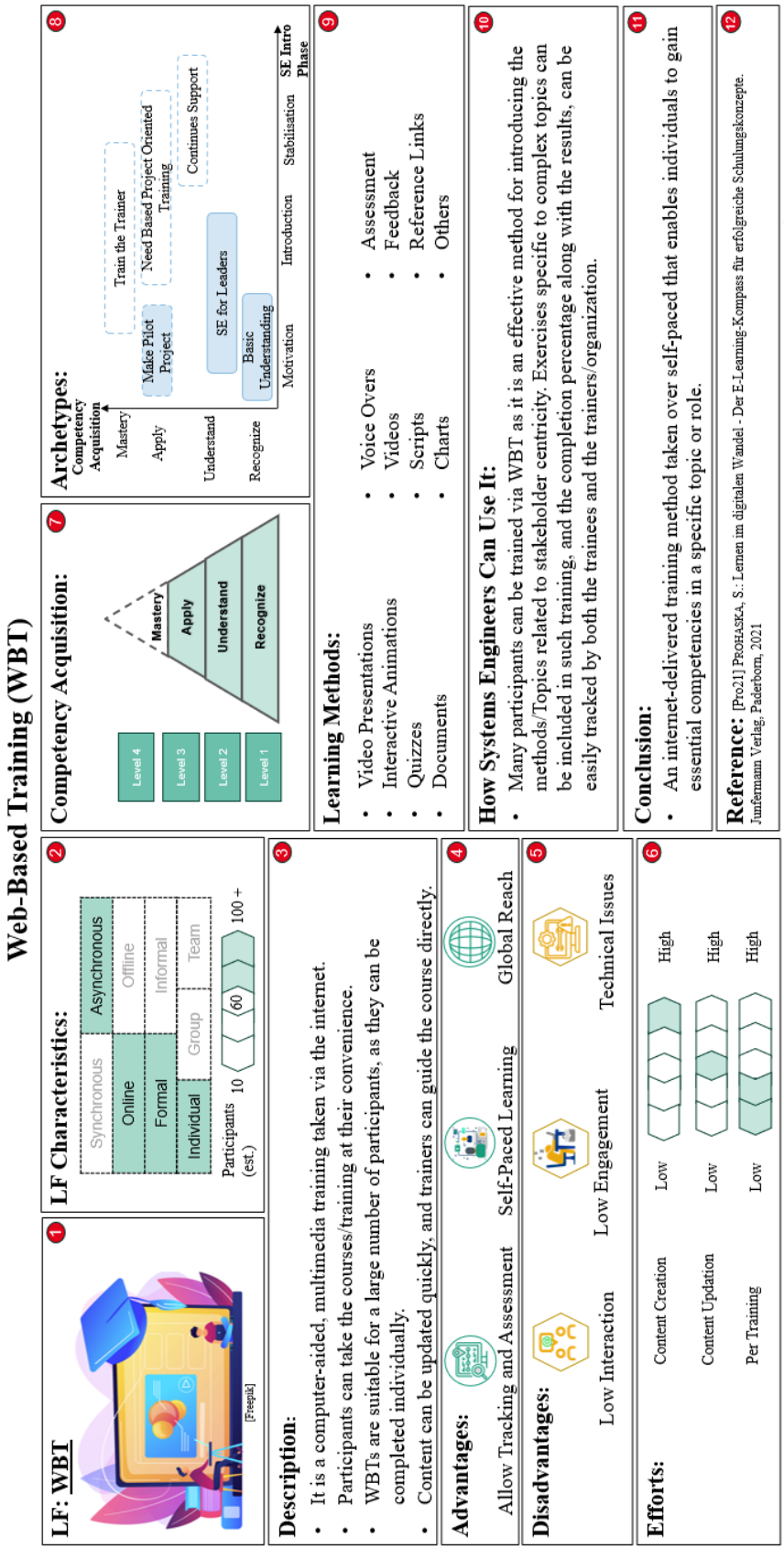
Learning Format: Conferences



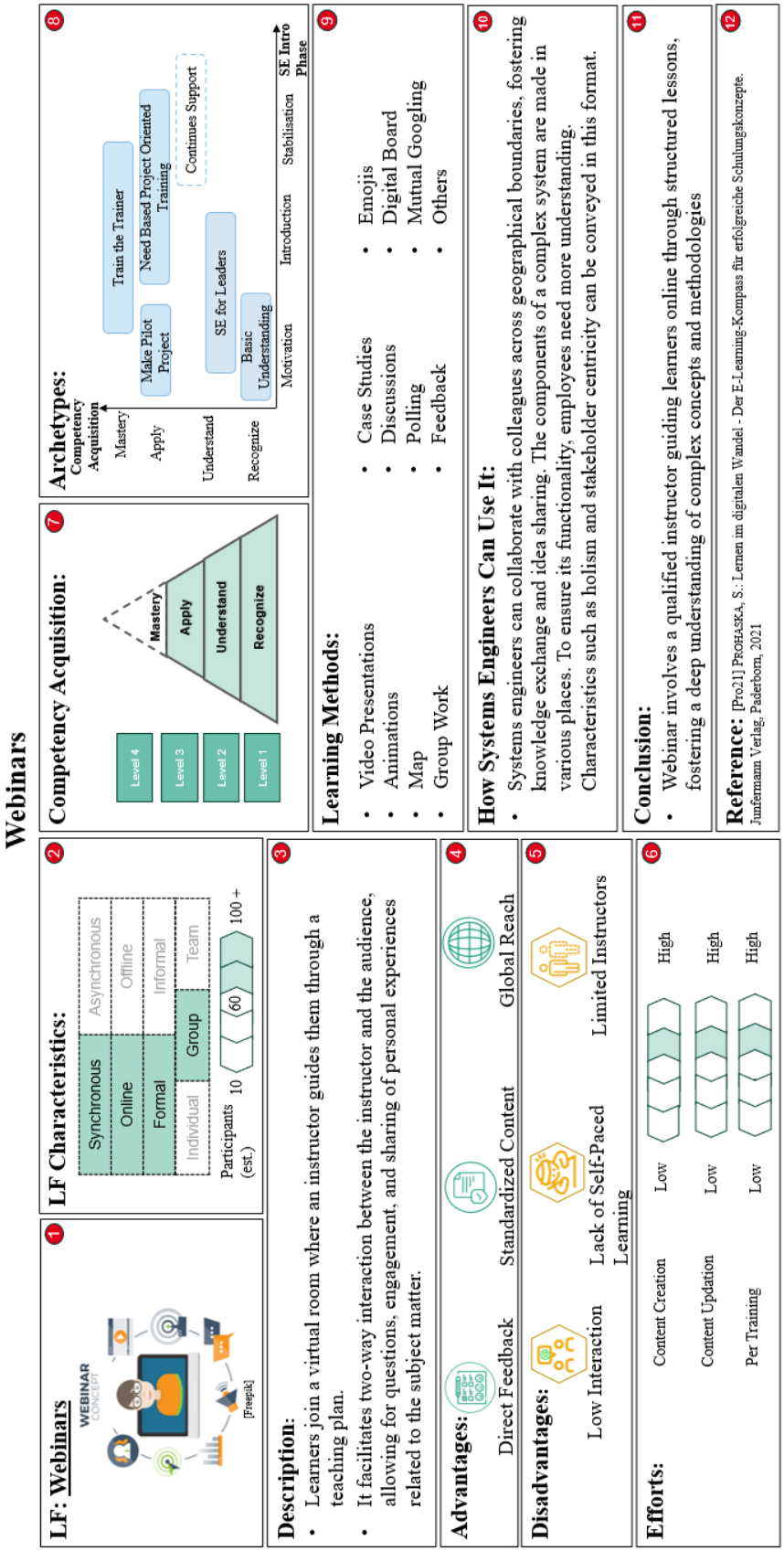
Learning Format: Computer-Based Training



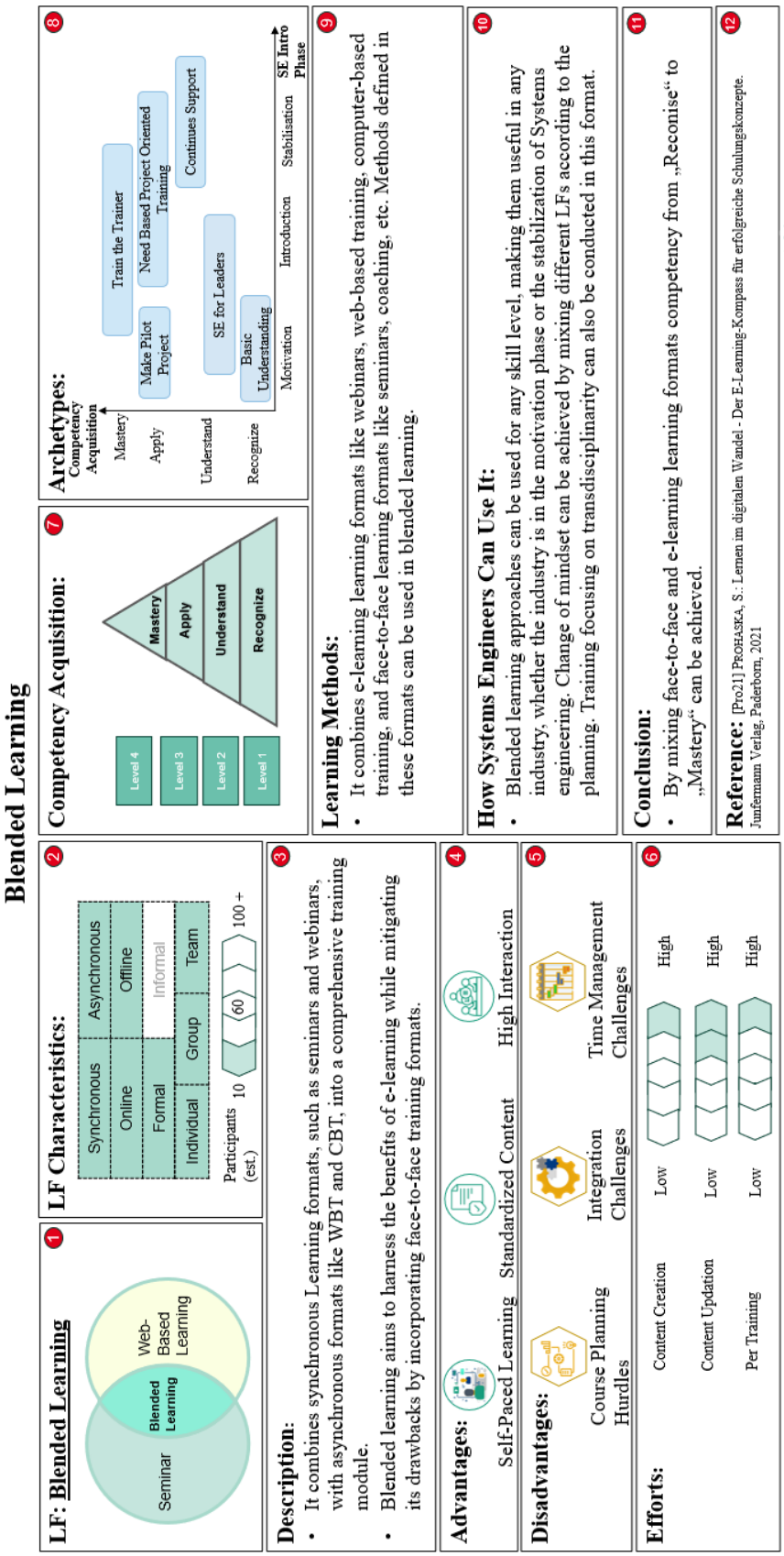
Learning Format: Web-Based Training



Learning Format: Webinars



Learning Format: Blended Learning



A4: Pairwise comparison of LF advantages

The LFs are suggested based on the results of pairwise comparison from advantages.