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Article

Systems Engineering Education: From Learning Program to Business Value

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Abstract: The complexity of delivering business value is increasing technically and socially. The increasing complexity triggers the need for an increase in systems competence in several roles within the technical domain. One of the core disciplines to focus on this competence is systems engineering, which gets increasing attention within the Dutch ecosystem to enhance individuals and organizations further in this competence. The challenge is a shortage of systems engineers and teachers in systems engineering. This study proposes a layered and integrated education offering with courses for depth and domain skills, multi-day programs with systems mindset and leadership capabilities, and tracks to broaden the knowledge to a broad variety of stakeholders. In addition, university colleges, universities, and other education providers have to cooperate in delivering cohesive education to all levels, e.g., bachelor, master, PhD, and lifelong learning.

Keywords: competence; mindset; education; systems thinking

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1. Introduction

Governmental and commercial organizations obtain increasingly powerful capabilities, for example, the diagnosis and treatment of pathologies, air defense against hypersonic missiles or drone swarms, and the production of high-density chips. The development of these capabilities and the involved systems are increasingly complex. The complexity is, among other factors, due to the further integration of systems (systems of systems), which are largely supported by digitalization [1], the scope increases from cyber–physical systems [2] to socio-technical systems [3] and a shortage of individual and organizational competence. This increase takes place in the development of systems and capabilities, e.g., in the organizations, processes, and humans with their individual human characteristics, and in the later life cycle when operating in a political, economic, social, technical, environmental, and legal (PESTEL) context. The increasing complexity triggers the need for an increase in competence.

Eindhoven in the Netherlands is a region where most of the Dutch high-tech industry resides, branding itself as Brainport. In the previous century, Philips Electronics was a conglomerate of many electronics industries, and its headquarters and research labs are in Eindhoven. A proliferation of high-tech industries emerged from the mother company Philips. A whitepaper by the Dutch organization for applied science (TNO) [4] states “The Dutch high-tech industry is R&D-intensive and characterized by the design and manufacture of complex products produced in small volumes. It often involves complex systems engineering and uses complex partnerships, value chains, and value networks. The high-tech industry’s products and services are used as inputs for the manufacturing of semiconductors, medical instruments, and data communications, among other things”. Most companies are in business for business, whereas in many other domains, businesses deliver for governments or consumers.

In 2002, the three large high-tech companies in the region, TNO, and the three technical universities established an institute for Embedded Systems Innovation (ESI), nowadays a part of TNO, as an open innovation center to learn about system complexity by research, education, and sharing activities. The full name is TNO-ESI, which is referred to as ESI for brevity. Since then, increasing technical complexity, pushing boundaries, and organizational complexity around partnerships, value chains, and across geographic borders added more complexity.

In this article, we give a descriptive retrospective of the programs for developing systems and leadership competence in the Netherlands to serve as a baseline for the future evolution of education. Competence is a factor at the individual and organizational levels. This article describes the program's evolution to determine critical (success) factors in developing technical leadership and systems competence to deal with increasing complexity.

The main research questions for this study are:

- What content should education offer to participants in order to enhance their competence in technical leadership and systems in their organizations?
- What are the transformations of the ecosystem in the last decades and how did that affect their needs for transformation support?
- How did the ESI programs evolve during the last 20 years because of these needs?
- What portfolio of educational offerings fits an industrial high-tech ecosystem?

2. Research Method

In this paper, we focus on a descriptive study, using data on the systems education that ESI provided in the last twenty years complemented with relevant desk research around context, complexity, and competence and development programs. We analyze the evolution of education by looking at the following main aspects:

- The type of company of the participants;
- The educational content;
- The educational format, contact hours, duration, and study load;
- Trends over time.

The data come from the administration archive, e.g., the date, registration of participants, the company, the type of education, and documentation about the education, e.g., its content, format, duration, and study load. The registration data are precise and consistent. The documentation of the main education is clear and well defined. However, specific customizations are less well documented. That is a limitation for the analysis of course content and format, duration, and study load. The course administration data are confidential.

The original data are rather detailed, e.g., how many participants per course per company or even business unit within a company. We have classified companies into types of companies: Original Equipment Manufacturers (OEMs), suppliers, service and people providers, research and education, and others. Nearly all of ESI's partners are OEMs. Service and people providers is a broad category, including people secondments, IT companies, and consultancies. The OEMs benefit from a broad ecosystem of suppliers: service, people, research, and education providers. Many suppliers are first-tier suppliers with a strategic relationship with OEMs. The classification of a company in a single category is a simplification; large companies may have internal providers belonging to another category. However, this classification is a good approximation.

The analysis classifies the educational content in the categories system, leadership, business, project management, domain, and depth. The system encompasses systems architecting-oriented content, e.g., methods, techniques, representations, and processes; the system is a mix of technical aspects and business and process insights, e.g., the context. Leadership ranges from professional skills to leadership competence. Business is the commercial and innovation perspective, including the life cycle of business. Project management addresses planning, managing resources, organizing the project, et cetera, e.g., the practical methods and techniques to run projects. Domain is knowledge about the application domain of the company, e.g., healthcare, semiconductor equipment, or printing; domain knowledge is company-specific and provides context insight into the systems that these companies develop. Depth is more specialized technical knowledge, often monodisciplinary (software, electrical, mechanical). This classification is not fully orthogonal; for example, business aspects fit in the business, system, and project management categories. However, the classification is good enough to see trends over time.

We employed two master's students to study the effectiveness of the education. Hoang [5] and Poort [6] used semi-structured online interviews with open-ended questions. Hoang had 13 voluntary participants from the programs between 2008 and 2019, and Poort had 14 voluntary participants from the programs between 2017 and 2019. The participants came from three different OEMs.

3. History and Context

3.1. High-Tech Company Ecosystem

OEM companies, suppliers, and providers in the high-tech industry in the southeastern part of the Netherlands have many formal and informal relationships. From there, the relations are subsequently spread out over the rest of the country. There is a wide variety of providers, e.g., service and people providers and research and education providers. The Dutch government actively stimulates cooperation, for instance via roadmaps, such as the HTSM Systems Engineering Roadmap [7]. Companies share suppliers with specialized capabilities, e.g., for developing and producing electrical and mechatronic components and for developing embedded software. Over the past decades, a de facto infrastructure has developed, facilitating a variety of high-tech systems developments. The geographical closeness of companies and research and educational institutes fosters a network of personal relations between employees across organizational boundaries. The concentration of companies on multi-company campuses further stimulates cross-company contacts. Figure 1 shows the location of the major OEMs and research and educational institutes in or related to the ecosystem. For comparison, it shows Silicon Valley on the same scale.

3.2. Trends and History

The Brainport region is building on a long legacy of the Philips business. Philips grew from a lamp bulb factory in the late nineteenth century to a huge industry conglomerate in the 1960s and 1970s in the previous century. At that time, companies were still vertically integrated. Philips was a conglomerate that covered the full range from technology research to the delivery of systems. Nowadays, we see an ecosystem with a wide and varied network of suppliers and IT, consultancy, education, research, and service providers. Table 1 shows today's companies in the ecosystem with some of their main characteristics. Large multinational companies have bought most of the ex-Philips companies, and the table shows the year of this spinoff. Around these companies, many suppliers and providers have grown, forming a high-tech ecosystem together.

If we position typical projects of these companies in the Novelty, Technology, Complexity, and Pace (NTCP) diamond [8], we see:

- Novelty: mostly platform;
- Technology: mostly high-tech, with some super-high-tech;
- Complexity: mostly system with some array;
- Pace: widely varying.

Figure 1 shows the partner companies and the research and educational institutions on a map of the Netherlands. Eindhoven is the heart of Brainport, and other partners are within a 2 h traveling distance. The Brainport area provides 445 thousand jobs, about 5% of the Dutch job market. ASML (20 k) and VDL (17 k) are the biggest employers.

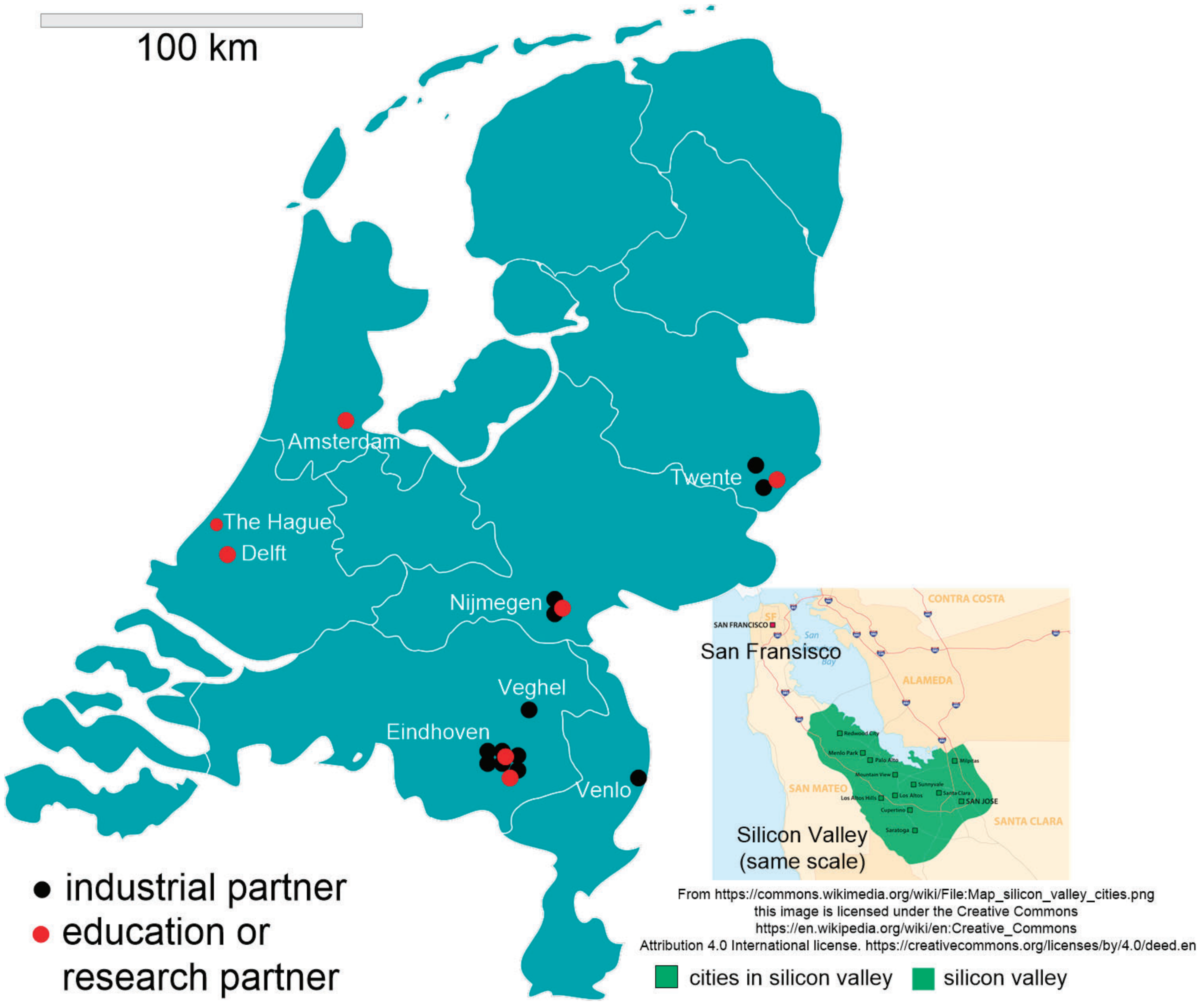

Figure 1. A map of the Netherlands with the main partners of ESI. For comparison, the map on the bottom right shows Silicon Valley on the same scale.

Table 1. Today's high-tech companies in the ecosystem.

Company Name	Year of Spinoff	Domain	Examples of Systems
Philips	-	Healthcare	X-ray, MRI, and many more
ASML	1984	Semiconductor	Lithography equipment
Thermo Fisher (Eindhoven)	1997	Scientific instruments	Electron microscopes
NXP	2005	Semiconductors	Chips for automotive, industrial, mobile, and communication infrastructure
Signify	2015	Lighting	Lamps, LEDs, and armatures
Thales Naval (Hengelo)	1990	Defense	Radar, command, and control
ITEC	2016	Semiconductors (was part of NXP and Nexperia)	Die bonders and sorters
Malvern (Almelo)	2002	Scientific instruments	X-ray diffractometers and X-ray fluorescence spectrometers
Kulicke and Soffa (Eindhoven)	2001	PCB manufacturing	Manufacturing equipment
Canon Production Printing		Graphic arts	High-volume printers
VanderLande		Logistics	Warehouses and luggage handling
DAF		Automotive	Trucks
VDL-ETG	2006	Manufacturing	Reticle handlers

Philips selling its variety of businesses resulted in a decrease of 412 k people worldwide in 1974 to 77 k people in 2022; the number of employees in the Netherlands decreased from 91 k to 11 k in the same period. ASML has been growing over the past decades from about 2 k Dutch employees in 2000 to about 20 k in 2022.

3.3. Population

The high-tech industry employs people with a bachelor's, master's, or PhD in engineering and science for research, product development, and advanced manufacturing. The employees come from all over the world. The Dutch educational system does not produce enough Dutch candidates to fulfill the industry's needs. There is some mobility between the companies.

3.4. Organization and Process

Most companies use or used a phase gate process. The introduction of agile processes, such as SAFe (https://scaledagileframework.com/ (accessed on 11 September 2023)), results in a mix of phase gate and fast-cyclic approaches that have not settled yet into a new stable way of working. Typically, the organization is a matrix with program and line management axes. Given the multi-dimensionality of most domains, the organization form may be more complex than a two-dimensional matrix.

The industries in this region used the terms project management, systems management (for the organization and processes), and systems architecting (for leading the transformation of the customer needs, business, and life cycle needs into a system specification and content-wise design). In today's world, the term systems engineering covers the combination of all three terms.

3.5. Challenges for Systems Competence

Multiple trends together form challenges for the high-tech industry:

- The pace in the market is increasing and the time from idea to delivery has to decrease;
- The pace of technology developments is increasing, which is visible in many technologies, e.g., material science, bio-medical, pharmaceutical, electrical, and a plethora of digital technologies;
- Supply chains have become supply networks with many interdependencies between parties in the network;
- Capabilities require increasing interoperability of many systems; systems of systems engineering addresses this challenge.

Digitalization is an underlying enabler for most of these challenges. The collaboration of conventional systems approaches and digitalized solutions is a challenge. Many organizations need more people in response to the above challenges. A side effect of organizational growth is specialization and a more fragmented stakeholder field; we obtain more silos of silos. Growth requires that people have to get up to speed, e.g., know the business, applications, and systems and the organization and its processes and culture. Societal challenges, such as sustainability, increase the scope of concerns for systems development, introducing more political, social, environmental, and legal factors.

3.6. Education and Research Ecosystem

Universities and university colleges are the prime knowledge holders, researchers, and educators. They tend to be discipline-oriented, which is a challenge for transdisciplinary competencies. As a consequence, a challenge for universities is that the actual competence, in the form of tacit knowledge, is in the practicing organizations. This tacit knowledge is often more holistic and less structured.

Governments organize applied science in knowledge and research institutes, for example, Fraunhofer in Germany, SINTEF in Norway, and TNO in the Netherlands. Transdisciplinary competence has a strongly applied nature; the context of application plays a significant role.

Many large organizations have factored out the competence development in their organizations, forming corporate-level "universities or academies". This means that they have created corporate-level departments, so-called universities, which are responsible for the education options and infrastructure. These universities are often intermediates between education providers and the targeted individuals, teams, or departments.

Lastly, there are commercial education providers. Traditionally there are many commercial providers for personal development and leadership. These providers serve a broad target audience without a specific understanding of high-tech systems development. There are several commercial providers in the region with a specific focus on high-tech systems. They mostly offer a variety of courses, ranging from technical to systems and professional skills.

In 2023, the Dutch government funded a national program called NxtGen HIGHTECH (https://nxtgenhightech.nl/ (accessed on 11 September 2023)). In this program, there is specific attention to exploring and building the systems engineering competencies with and for this whole ecosystem.

3.7. The Evolution of the System Competence Development

ESI built its education on existing courses and programs in the region. For instance, in the late 1990s, Philips had multiple courses and programs to advance the systems architecting competence. A week-long systems architecting training was one of these courses [9], resulting in the textbook [10]. Another was a hybrid program consisting of on-the-job experience and short education events called the architecture school. We see the following main developments over the past 25 years:

- The ambition of the programs has increased from an individual development level to an organizational and business level. The mission is to actively support the ecosystem to cope with the ever-increasing complexity of their products (https://esi.nl/about-us (accessed on 11 September 2023));
- The content changed from more technical and system toward more system and leadership;
- Case-based working and reflection are essential elements in the course pedagogics;
- Over the years, the target groups of ESI programs became broader. In the beginning, we aimed mainly at systems architects; now, we also include a broader set of stakeholders, e.g., systems integrators, group leaders, management teams, and sponsors of (team) assignments;
- The duration of some programs grew and now ranges from a few days to nine months.

The strength of the architecture school was the combination of courses (offering knowledge and facilitating skills development) and on-the-job work experience (allowing ability and attitude development). The weeklong courses work well for people in the industry. Participants are not available for regular work for one week. In that week, they obtain a boost in knowledge and skills. Participants were typically still early in their careers.

ESI broadened the scope of the courses from only Philips to courses with participants from various companies. These multi-company courses bring the benefit of an exchange of experiences between non-competing companies. However, the increased diversity of applications and systems makes it more difficult to go deep into various topics. There is a tradeoff between depth in domain specifics and learning from other domains.

The next step was to extend courses into a competence development program (CDP). A CDP consists of several multi-day modules. Participating teams work on a case during and in between the modules. The case is the main learning vehicle. A good case fits the actual needs of the company and has a strategic impact. It connects the customer, business system, and technical views. The scope of the program also broadens with professional skills and business. To support this variety of competencies, the program uses a schedule where a few teachers with industrial backgrounds and different competencies alternate. ESI runs CDP as an in-company and multi-company program. Teachers for business and systems architecting have significant industrial experience.

The growth of online learning triggered the development of blended learning formats. This fitwith the globalization of systems engineering activities that stimulated the use of online training formats. ESI now offers programs in various formats (face-to-face, blended, and online). When COVID-19 hit, there was a sudden higher demand for online possibilities. Funded by the EIT-Digital European program, ESI started to develop blended learning in 2015 [11]. Teachers and learning and development experts together redesigned the course structure. The teacher repartitioned the fine-grained learning material from presentations that are the equivalent of 15 to 30 min of lecturing to about 5 min. The smallest part is a nugget with about 5 min of video and little other material, such as a brief descriptive text and activating or reflective questions. The main challenge of this transformation is the condensation of the course material to the essence to ensure that the material fits the attention span of the participants [12,13].

The foreseen benefits of blended learning are more focused on active learning in physical workshops and scaling up and less traveling for knowledge transfer. The typical use of the blended material is packaging the material at multiple levels, e.g., foundational material for starters and more remote stakeholders, further elaboration for professionals, and full competence focus, e.g., in combination with physical workshop(s) at the highest level.

In 2017, ESI started to integrate the teaching of companies further. In the in-company program, both the leadership and the systems teacher were present together continuously. The benefit is that participants learn leadership and architecture in relation to each other.

The program serves multiple goals for companies:

1. Build an internal network to fit the size of the companies and their global presence. All our partners have premises all around the globe. For instance, ASML is present in the Americas, Asia, and Europe;
2. Develop individuals and try to broaden their system perspective;
3. See who is willing and capable to step up and take more ownership within the company: who are born leaders and how do they lead?
4. Explore hot strategic topics. Participants use this as a learning carrier that creates company value at the same time. We have seen examples where the outcome really went to the market (https://www.linkedin.com/posts/dumitru-daniel-popa-a31b24b_nxp-blog-secure-car-access-with-uwb-ready-activity-7059406239033679877-umvF (accessed on 11 September 2023)).

In 2021, the program expanded to mixed-supplier OEM teams. Working with teams across organization boundaries is a step toward recognizing the role and importance of the ecosystem.

Also in 2021, the program increased the focus on enhancing organizational learning. Often-repeated feedback from the participants is that individuals learn; however, since the organization around them has not gone through the same development, individuals find it difficult to apply what they learn. One of the approaches is offering programs to a broader audience.

3.8. Communities of Practice

For the lifelong development of competence, we see communities of practice (COP) in and between companies as a vital ingredient. However, maintaining lively COPs is challenging. A long-running COP is the System Architecture Study Group (SASG) (https://sasg.nl (accessed on 11 September 2023)), facilitated by ESI. The SASG has been operating since 1997 with a steady rhythm of three meetings per year. The SASG has over 250 members with a role in systems architecture or engineering. Around 30 to 35 participants are present per meeting.

The systems architecting events that Philips organized for past participants evolved into a yearly ESI symposium (https://esi.nl/events/symposium (accessed on 11 September 2023)) with more than 300 participants. Moreover, there are multiple Special Interest Groups active. SIGs are smaller and have a clear focus, like performance, system and software testing, and software rejuvenation.

3.9. Envisioned Individual Development

Figure 2 shows how the program envisions the growth of individuals. The vertical axis is a scope axis. At the component level, engineers are primarily engineering in a relatively well-defined context and problem space. Engineers act as part of a team. At the (sub) system level, the context is more dynamic and complicated. This requires design and architecting behavior, as well as a change leader mindset. The time and attention spent on content is reducing in favor of context and mindset. When developing further, this reduction continues, to allow for sufficient market and business understanding and to provide thought leadership to the broad set of heterogeneous stakeholders.

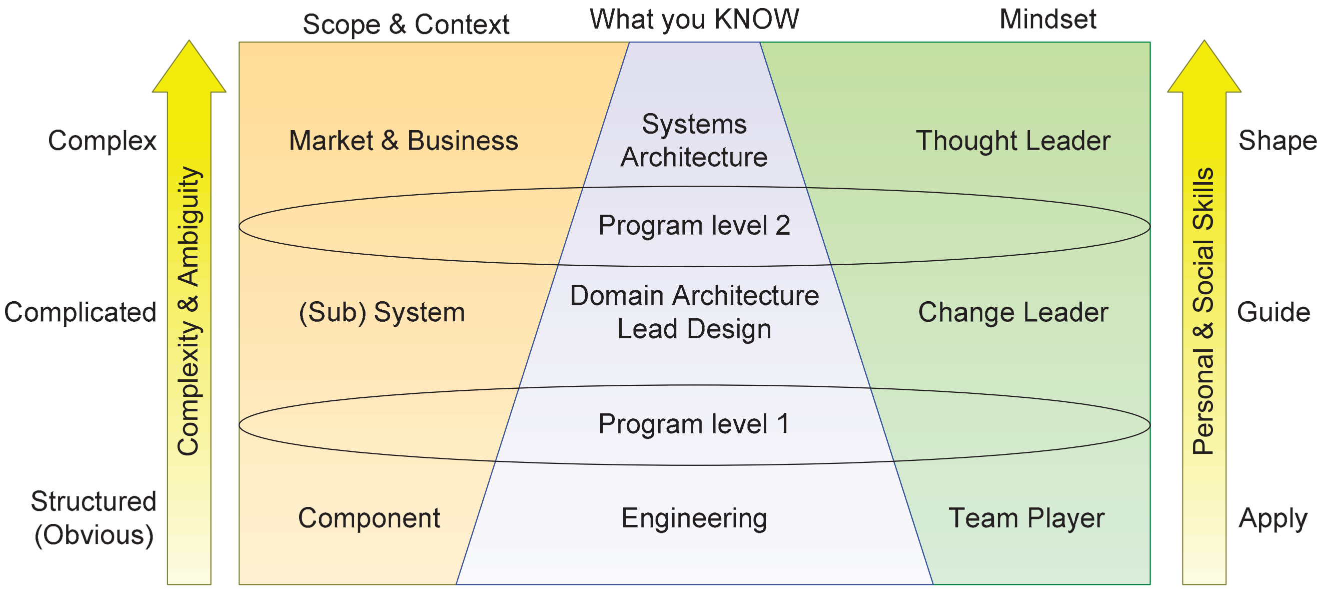

Figure 2. The envisioned growth path for individuals.

4. Theoretical Framework

4.1. Context, Organizational Development, and Way of Working

This section starts by discussing the broader context, organizational development, and way of working. Next comes the complexity perspectives. Then, it zooms in on developing people for organizational performance and ends on the competence of a systems engineer.

The Netherlands is part of mainland of Europe and, regarding size (41.850 km^2), is a small country. Nevertheless, the Netherlands has a high Gross Domestic Product in relation to its 17 million citizens of around EUR 61 k per capita [14]. The Dutch socio-economic model belongs to the countries that originate from the Rijnland model [15] or the social market economy [16]. Countries like the Netherlands flourish because of their success in socio-politics, innovation, and entrepreneurial spirit [17]. The Rijnland model entails a coordinated market economy where different stakeholders come together and influence the way business should be done and what is expected in society. Moreover, the structure of the top management in companies differs from the Anglo-Saxon model; the Rijnland model uses a two-tier board, whereas the Anglo-Saxon model uses a single tier. In the 1990s, the countries with a merely Rijnland focus (Germany, Switzerland, and the Scandinavian countries) shifted to an Anglo-Saxon focus where the shareholder was at the center of the model [18]. However, the underlying values of the social market economy are still engrained in how organizations work and their culture. The social market economy thus still has its influence on the organizations that are founded in the Netherlands. Van Bavel [19] states that an open society with social and political openness (equality) comes before a market economy can arise.

As with any other industry, the different organizations in the high-tech industry are undergoing phases of change for several reasons during the last decades, as written in the history section. Greiner [20] defines five key dimensions in the development of an organization:

- Age of an organization;
- Size of an organization;
- Stages of growth;
- Stages of crisis;
- The growth rate of the industry.

These dimensions come together in a scheme to show the interaction between these dimensions. If companies do not overcome a certain crisis or make wrong decisions regarding the appropriate interventions, decreased acquisition or even bankruptcy is on the lookout. The dimension of age is clear; organizations change in time and different organizational practices are necessary. Greiner [20] provides a classic example of centralizing and then the need for decentralizing activities. Moreover, he addresses that with the aging of the organization, the culture and mindset can get stuck; then, change is harder to accomplish. Within the stages of growth and crisis, this can be about making sure the work gets done (efficiency) and making sure the work gets done effectively (with the right collaborations and alliances). Greiner's model provides these stages with the necessary intervention steps that are focused on, e.g., direction and collaboration.

Phelps et al. [21] reviewed the life cycles of growing organizations. They found that there is much literature about different stages that suggest processes are linear. However, there is not a lot of research validation behind these stages. Phelps et al. prefer to use states instead of stages with two dominant terms: tipping points and the absorptive capacity of an organization. Tipping points are events that require action or change (this can be growth or other external developments). This can be realized by people management, new market entry, obtaining finance, the formalization of systems, strategic orientation, and operational improvement. For this, they have to find and acquire new knowledge and put it into practice. The second term, absorptive capacity [22], refers to how well the organization can respond to tipping points. "Thus, prior related knowledge confers an ability to recognize the value of new information, assimilate it, and apply it to commercial ends. These abilities collectively constitute what we call a firm's absorptive capacity". Absorptive capacity can be realized through several mechanisms, such as an R&D department, giving input for acquiring new knowledge, direct involvement in manufacturing, and training people in new skills. Building up capabilities starts with ignorance, awareness, information, knowledge, and implementation.

4.2. Complexity Perspectives

Complexity in developing systems has many drivers that decompose within different disciplines and external and internal layers. Defining these different layers of complexity can offer support for targeted interventions when dealing with complexity within an organization. Secondly, the technical complexity of the high-tech industries' products adds to the total complexity. Lastly, the Cynefin framework from Snowden [23], see Figure 3 ties the social and technical aspects together at a higher abstraction level. It describes the levels of complexity and which activities to do in a certain situation. This requires having a sense of what the level of complexity is and what way of working may help navigating successfully through a certain event.

In the Netherlands, ESI nowadays uses the term cyber–physical systems, showing an increase in software in and around the originated hardware systems (ESI Symposium, 2017, Managing Complexity). Törngren and Sellgren [2] sketch the history of the term cyber–physical, which goes back to the year 2006 in the US, for systems integrating computation, networking, and physical processes. They focus on the technical complexity of the system and name the most discussed facets, like the heterogeneity of the components and their interactions, uncertainty and emergence from putting components together, and dynamics.

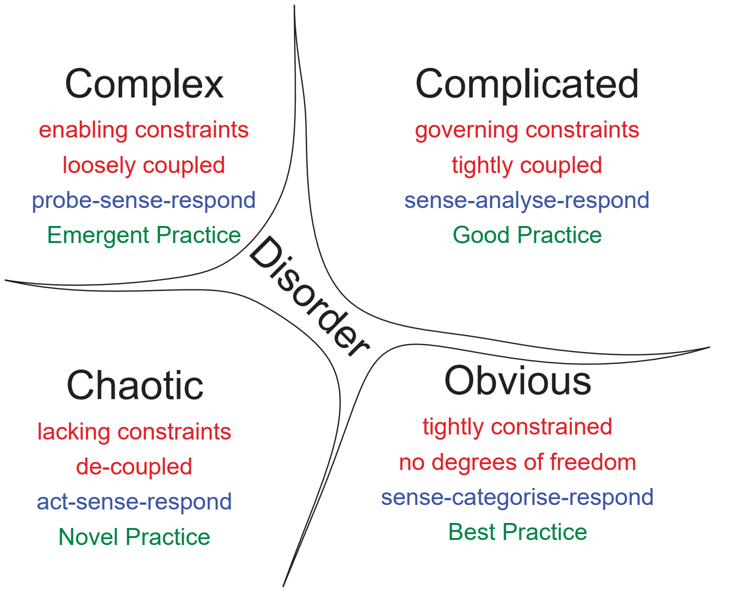

Figure 3. The Cynefin framework from Snowden, 2003 [23].

The cyber of cyber–physical has increased over recent years, moving some of the functionality to software somewhere on the network. In the products of today, software is an integral part of the product. The rise of software happened mostly in the last six decades. Late last century, software development adopted an agile way of working. In the last decade, organizations have applied agility on a large scale [24]. A lack of focus on the human side of software development triggered this specific way of working. It puts the human back in the middle again, regarding software development [24].

To grasp the full system in its changing context to be fit for purpose and continuation of a business, systems engineering plays a crucial role in managing this system's complexity. INCOSE [25] gives the following definition of systems engineering: "Systems Engineering is a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods".

Pyster et al. [26] refer to the horizontal technical dimension of a system that involves customer engagement and preferences, which impacts the whole set of the system, such as requirements, architecture, trade-offs, and more.

4.3. Developing People for Organizational Performance

This depends on how well an organization can respond to these different kinds of complexities and changes that are presented. Prahalad and Hamel [27] developed a theory that organizations should derive their strategy from their core competencies. "Core competencies are the collective learning in the organization, especially how to coordinate diverse production skills and integrate multiple streams of technologies". (p. 4). Determinants of the core competencies are related to customer advantage, uniqueness, and potential access to the world market. The core should be clear, and anyone who works for the company should have a clear view of the needs of the customer and what is technologically possible. This then plays a further role in the development of the right competencies for individual employees. As shown above, for developing complex high-tech systems, systems engineering (SE) plays a crucial role in the core competencies. However, the focus of most universities lies in one of the monodisciplines, so systems engineering is mostly practiced and developed by the high-tech companies themselves. Developing SE professionals mostly happens during their working life.

If we take a closer look into the learning sciences, there is a high interest for on-the-job learning: learning happens every day and can happen everywhere. Eraut [28] stipulates that most of the learning happens on the job, but employees (people they have interviewed) make a vast distinction between learning and working activities; they do not overlap (p. 249). Within the scope of work, Eraut focuses on different forms of informal learning, which he puts in the context of a continuum from formal learning with in-the-middle activities, like mentoring and informal learning. Informal learning mostly touches on (1) learning from experience and (2) learning from others (p. 248). He characterizes this as unintended, implicit, and unstructured learning without a teacher. Several interventions can reinforce learning and organizational performance. Eraut categorized four types of work activities that (explicitly) focus on learning richness: participation in group activities, working alongside others, tackling challenging tasks, and working with clients (p. 266–267). One practical example is systematic reflection in the form of, e.g., debriefing activities after every team meeting individually or as a team. Also, in learning and HR programs, there is a lot of attention to mentoring, reflection, 360-degree feedback, and journaling. Vermeren [29] states "For developing leaders, for example, challenging tasks and reflection have been identified as effective".

Next to learning on the job or informal learning and on-the-job interventions, there is a general belief that investing in the development of people has a positive effect on organizational performance, such as investing in learning programs [30]. This statement is from 20 years ago. In that same article, they state that going beyond this statement, less research has been performed. A lot of learning programs exist out of several learning activities. These activities, however, do not have a close connection to each other as an integrated set of focused development opportunities [30]. Programs are intended for current or future work and intend to systematically support and grow competencies in order to reach their full potential for the goal of the organization.

Moreover, it is hard to really pinpoint what the contribution is from a single learning program, even if it exists out of multiple learning activities. It is hard to measure beyond the learning outcome of the program toward contributing to the business goals. However, Jacobs and Washington [30] show several study outcomes where investment in employees results in job satisfaction, commitment, and the ability to cope. Other ways of measuring the effectiveness of (learning) programs could be to look at promotions, retention rates, or flexibility in tasks/roles (p. 7).

As Prahalad and Hamel described, high-tech companies have a few core competencies that are of utmost importance. On the one hand, working on cross-cutting technologies, integrating those technologies and, on the other hand, getting them into a working system that is fit for purpose with the right functionalities and dealing with emerging behavior that arises by bringing the parts together. The latter is key for the development of systems engineers and their contribution to organizational performance.

4.4. Competence of a Systems Engineer

Systems engineers are one of the disciplines working on complex systems next to a diverse group of professionals. Systems engineers have the task of connecting customers, businesses (strategy), and system views in a given context so that the system is fit-for-purpose. Another cross-connection is to connect the strategy with requirements and architecture, as seen in Decisions Across Boundaries [31].

Systems engineers are spiders in the network of a company in order to fulfill the mission as INCOSE formulated it. Some personal traits, such as self-awareness and inquisitiveness, enable systems engineers to grow [32]. They develop proficiency through experience, mentoring, and education. The core word in this is the word system. There are many different attempts to describe the core skill and mindset in developing a (high-tech) system, namely systems thinking. A good system definition according to Arnold and Wade [33] should at least have the following three elements: (1) the purpose/goal or functionality, (2) the blocks or elements, and (3) the connections or relations between these elements. Pyster et al. performed a more elaborate study on what makes an effective systems engineer [32]. For this study, the researchers interviewed hundreds of professionals related to systems and systems engineers themselves in order to capture the most important behavioral patterns of an effective systems engineer. The categories that they identified were:

1. Math, science, and general engineering;
2. Systems domain and operational context;
3. Systems engineering discipline;
4. Systems engineering mindset;
5. Interpersonal skills;
6. Technical leadership.

These categories are scored on different levels of proficiency, and when filled out, they form a spider graph with individual scores. This can be used as a self-assessment or 360° feedback tool during someone's entire career with changing levels of proficiency over time. Moreover, if aggregated, it could give a company insight into where possible gaps are in the entire systems engineering workforce [34].

The Systems Engineering Research Center (SERC) [34] developed a guide where they give several examples of how companies have used their models, roles, and behavior. For instance, Rolls Royce, which already had a competency model, was compared and contrasted with the roles and proficiency model of the Helix team. One of the focused approaches that Rolls Royce took was the idea that systems engineering should be normalized over the entire workforce, with some competencies relevant to the total engineering community, such as curiosity, technical communication, planning/project program mining, and systems thinking (p. 17).

In 2018, Pyster et al. increased the scope of their research from individuals to organizations, exploring how organizations influence the systems engineering workforce. They used the Competing Values Framework and the Quality of Interaction Index (QI Index) to describe the culture of organizations. In 2019, Burke and Hutchison of the Helix team also performed this study on organizational systems engineering effectiveness in The Netherlands. Five high-tech industry companies and partners of ESI participated in this study. The overall observation was that the Dutch high-tech industry is somewhere in the middle of the Competing Value Framework and on the generative side of the Qi Index (upper right corner), with high psychological safety and high cognitive diversity. In the presentation for the ESI symposium of 2019 [35], they refer to the work of Pisano (slide 13), who stated that Dutch companies "manage tensions that when managed well support stellar innovation" as described by Gary Pisano in "The hard truth about innovative cultures".

5. Results

In the period 2003–2022, ESI provided courses, programs, and tracks. The Embedded Systems Architecting program (ESA) is the starting point; ESI inherited this program that has been running since 2003. ESI developed courses, programs, and tracks, evolving and extending the ESA program. All these programs target practitioners providing options for lifelong learning. The ESA program and the later-developed education do not result in formal credits, as opposed to a university education. However, the pedagogic format, learning material, and learning outcomes are close to the master's courses in the industry master's program in systems engineering at the University of South-Eastern Norway [36]. Table 2 shows a summary of most of them. The analysis focuses on systems engineering and, therefore, excludes specialized courses that ESI also provides. In-company programs are normally a variant of one of the programs in the table. Most in-company programs are not included in the table since they require customization. Courses are typically 1-week courses without any additional study load. Programs have multiple blocks of a few days of face-to-face learning. In between the blocks, participants are given some homework, which is often related to the case that runs throughout the program. Tracks use online videos and a few preparation sessions followed by a 3-day workshop. The tracks use a funnel approach, where many participants follow a small general subset of videos, and a medium-sized group follows an additional set of videos. A smaller core group participates in the 3-day workshop. The track participants who only watch videos are not included in the data in this section.

Table 2. Overview of courses, programs, and tracks that ESI provided from 2003 to 2022.

Program	Format	Content	Duration (Months)
Courses	5 days	Systems architecting, conceptual modeling, systems integration	0.25
ESA program	3 + 4 + 4 + 4 + 4 + 4 + 3 = 26 days	Stakeholders, SW, semiconductor HW, system	9
Program designer	3 + 4 + 7 + 3 + 2 + 3 + 5 = 27 days	Stakeholders, SW, HW, motion control, system, project management	14
Program domain architect	3 + 4 + 4 + 4 + 3 + 3 + 2 + 2 + 3 + 4 = 32	Technology and innovation management, systems architecting, software architecting, system integration and test, architecture and design, modeling and analysis, performance, reliability, supportability and logistics	15
In-company level 1	3 + 1 online = 4 days		6
In-company level 2	5 + 5 + 5 + 4 = 19 days	Architecting, leadership, innovation	9
In-company level 1 online	Online spread over time = 3 days	Remote, self-study, team coaching, teamwork, plenary readout	6
In-company level 2 online		Architecting, leadership, innovation	9
Systems and leadership	(2 + 3 + 2 + 2 + 1) days + 3 evenings = 11 days	Architecting, leadership	9
Track systems integration	Online videos and preparation + 3 = 4 days	Systems integration	1.5

Figure 4 shows the number of participants for the various types of courses over the 20-year period. Due to the timing of programs and the switch from the ESA program to the new open programs, no courses or programs finished in 2009, hence the lack of data for that year. This diagram shows a gradual increase in the total number of participants. The recent increase in participants is due to the introduction tracks. Track formats facilitate a broader rollout using the combination of online preparation and a relatively brief face-to-face workshop. The figure also shows the shift from courses to programs and tracks.

Figure 5 shows the number of contact hours instead of participants. The contact hours are participant contact hours, e.g., the number of participants * contact hours of the course, track, or program. This shows much less growth since the tracks have relatively few contact hours. Programs tend to have many contact hours, which makes them more visible in this figure.

We analyzed the type of participants using a classification of their employers. This analysis uses the ratio of the number of participants' contact hours; see Figure 7. OEMs form the major contributor of the participants. The suppliers of parts to the OEMs, labeled suppliers, have a limited presence, although there has been an increase in recent years. The ESA program that ESI inherited from Philips and the Technical University of Eindhoven attracted a significant number of participants from providers. ESA also attracted people with research or education jobs. In the past decade, OEM participants dominated, while the providers disconnected.

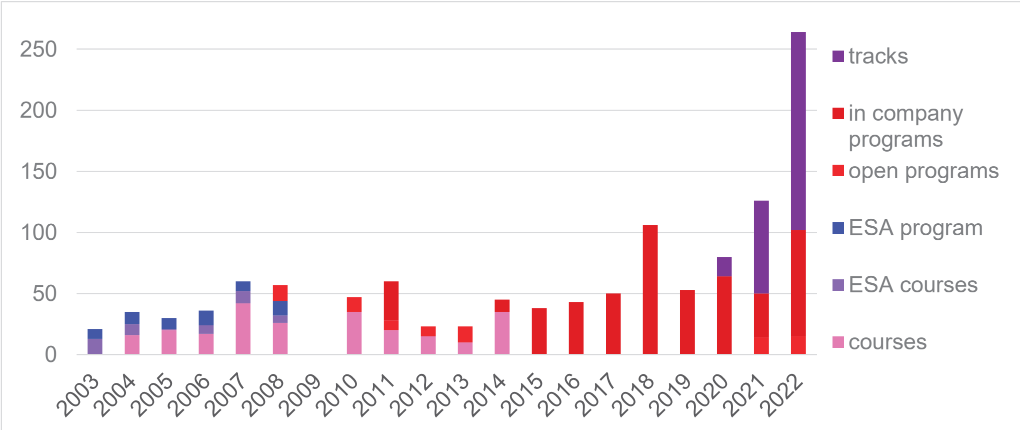

Figure 4. The number of participants per year for various types of courses, programs, and tracks.

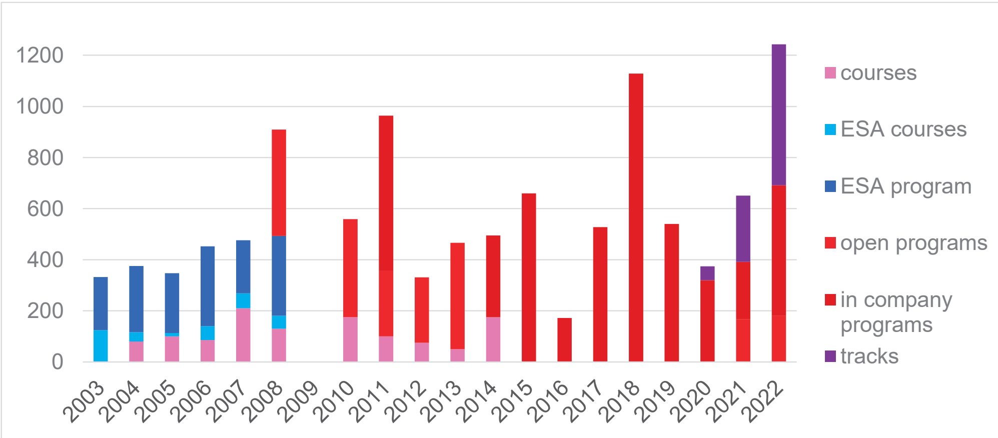

Figure 5. The number of contact days per year for the same classification as Figure 4.

Figure 6 shows the ratio between courses, programs, and tracks in contact hours. This figure clearly shows a decrease in courses and an increase in tracks.

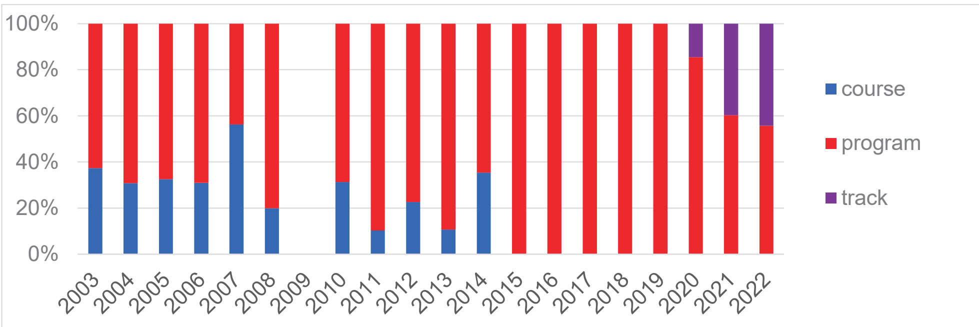

Figure 6. The ratio of participants' contact hours between courses, programs, and tracks.

Finally, we analyzed the content of the offerings over the same period; see Figure 8. This figure very clearly shows that depth content dominated in the early programs. The idea was that potential architects needed multiple knowledge pillars to stand on. The current insights are still that architects need sufficient knowledge of various disciplines. However, in ESI's vision, architects should gain that knowledge by self-study and taking specialized courses from a broad spectrum of providers.

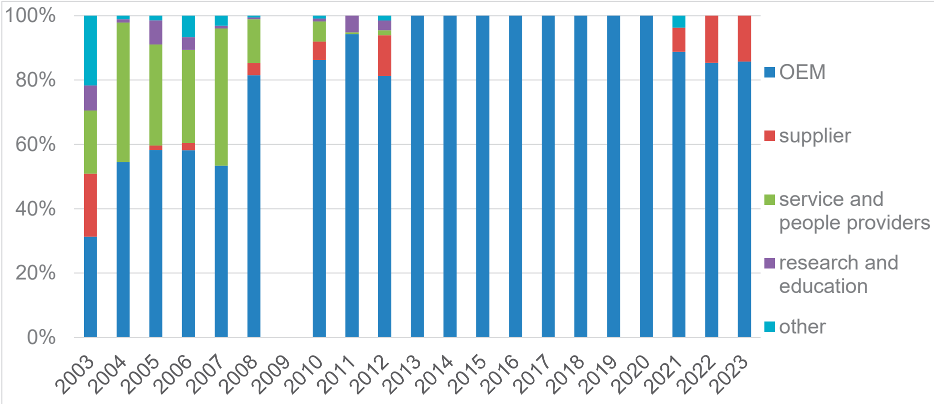

Figure 7. The ratio of the types of participants, using participant contact hours.

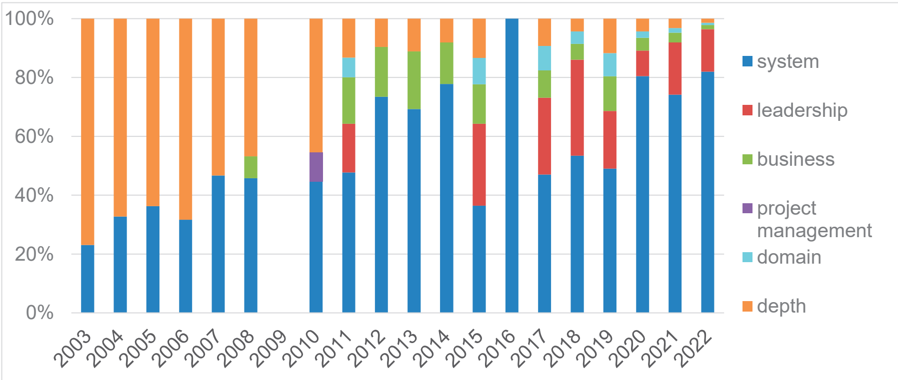

Figure 8. The ratio of the content, in participant contact hours.

Since 2008, some programs had a module on technology and innovation management, system supportability and logistics, or business and innovation. Since 2011, ESI has been using partners for professional skills and leadership. In recent years, we see that systems and leadership form the main content of the programs with some business content. Moreover, the way of teaching systems and leadership has also become more integrated and cohesive than in the years before where they were mostly loose elements taught without connection next to each other. Domain content is limited to in-company programs, where the company can clearly indicate what domain knowledge makes the most sense. Guest speakers from the companies are a common way to provide domain knowledge.

The analysis of the semi-structured interviews from the master's thesis projects resulted in the following conclusions:

- "The findings showed that how engineers transfer soft skills was influenced by individual cognitions, individual actions, work environment factors and additional personal reasons. The first three comply with what was expected from processes of change to a large extent. A further look at the interpretation of the processes revealed that individuals' job role was central to how they transfer soft skills." [6];
- "Furthermore, findings indicated that employability competencies are primarily developed through gaining work experience. Nevertheless, training programs add value by expediting the process of gaining experience and facilitating formal and informal networks." [5].

6. Discussion

6.1. What Content Should Education Offer to Participants in Order to Enhance Their Competence in Technical Leadership and Systems in Their Organizations?

Figure 9 shows the skills that Pyster et al. [32] propose for systems engineers: technical leadership, interpersonal skills, SE mindset, SE discipline, system domain and operational context, math, science, and general engineering. The table maps these skills of the course categories on ESI education. ESI classification depends on the teachers delivering the education. Hattie via Vermeren shows that a teacher has big effect sizes on the outcome and effectiveness of the program; for instance, teacher clarity (d = +0.75), teacher–student relationships (d = +0.73), and task feedback from the teacher (d = +0.74) [29] [p. 1108]. Consequently, most leadership and professional skills belong to the same class of personal development. Experienced systems engineers deliver system-oriented skills and mindset. Separate teachers with a business or project management background deliver these skills. Finally, specific subject matter experts deliver domain or specific science or technology knowledge and skills. The challenge is to connect all these different parts into one whole. The program manager or lead teacher normally fulfills this role.

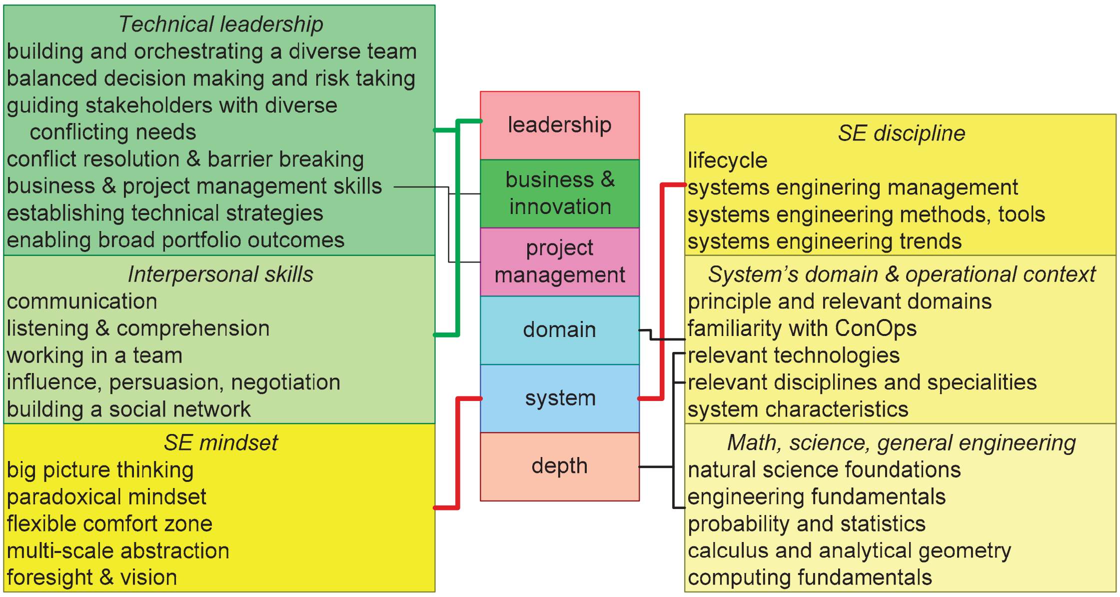

Figure 9. Mapping the Helix competence areas on the classification used in this paper. The colors correspond to Figure 8.

Figure 8 shows that most of the education is moving from depth to system and leadership, with some business and innovation. Working on cases serves as the link of connecting to the domain. Some company-oriented programs add some domain content via guest speakers and case owners who introduce the case.

Eraut [37] describes engineers as "excellent hunter-gatherers of knowledge and resources". We assume that engineers who enter our education have a sufficient foundation in math, science, and general engineering. They may need more specialized knowledge that they have to find through this hunting skill; this may take many forms, e.g., asking subject matter experts, reading books, following courses, et cetera. These needs are so specific for individuals that we do not include them in the education.

We obtained feedback from participants that the total load of training and work is (too) high. In-company skills training on top of the system competence development and a high workload causes this high total load. As a consequence, education needs careful selection; time, individual cognitive capacity [38], and organizational absorptive capacity [21] are scarce resources.

Altogether, we see that the emphasis is shifting to competence in technical leadership and interpersonal skills together with an SE mindset and, to a lesser degree, SE discipline. Some business and innovation content are necessary to fulfill the development path in Figure 2. However, there are other organizational roles, e.g., marketing and products. Business or innovation managers primarily own businesses and and innovative; participants should learn enough to cooperate with them. Figure 8 shows the evolution toward this mix of content.

To enhance the competence in technical leadership and the systems of individuals in their organizations, education has to focus on leadership, interpersonal skills, and an SE mindset while paying sufficient attention to business and innovation and providing some SE discipline knowledge. This approach requires that more education or learning opportunities on the job are available for less experienced employees in SE discipline, domain, and depth of knowledge and skills. Eraut [28] mentions that organizations should focus more on and include informal learning activities within the workplace. For example, ESI tries to include such mechanisms by adding more focused learning activities to their daily work, e.g., a three-day workshop to kickstart a new development cycle with a project team. This has the advantage that it is treated more holistically, it is easier to transfer because it is already closer related to their daily work, and feedback and support are easier to accomplish. The findings from Hoang [5] and Poort [6] support the relevance of the combination of informal learning and education.

6.2. What Are the Transformations of the Ecosystem in the Last Decades and How Did They Affect Their Needs for Transformation Support?

Of the companies in Table 1 ASML, VanderLande, and VDL-ETG are fast-growing companies in the region. All other companies in the region experience more moderate growth rates or even experience temporary reductions. ASML is partially super high-tech, with some breakthrough project systems fitting in arrays and time-critical projects. VanderLande is moving from derivative to platform, mostly low- to medium-tech, and array complexity and the market are moving from regular pace to fast/competitive. Both VanderLande and ASML are actively involved in the open programs and the learning tracks. VDL-ETG is novel, high-tech, and complex.

According to the dimensions Greiner mentions [20], the high-tech industry flourishes because of the high demands of society. The New York Times [39] used to call ASML an obscure company. Dealing with such high demands, ASML had to grow rapidly and let the organization structure follow the machine, following Conway's law [40]. ASML uses several organizational and process mechanisms to stimulate cross-collaborations among departments and several learning programs across the company. When there are economic headwinds, companies may not be able to afford education. The need for education remains. Hence, during a crisis, companies often freeze their learning programs, as ESI has experienced in the past.

Figure 7 shows that ESI served a variety of OEMs, suppliers, and providers. However, gradually, the focus moved entirely to OEMs. In recent years, we have seen a slowly growing awareness that complexity requires that the growing ecosystem as a whole has sufficient competence. OEMs have a need for suppliers and providers to grow their competence as well. OEMs also have a need for the suppliers and providers to interoperate well with the OEM organization. In the last three years, we have seen combined supplier–OEM teams in the programs to achieve this. This reasoning suggests that education should extend even further than OEMs and suppliers; it should also include providers.

6.3. How Did ESI Programs Evolve during the Last 20 Years Because of These Needs?

The organizational and resulting social complexity requires technical leadership, which in turn requires sufficient professional skills. Hence, the programs increase the time spent on leadership and professional skills as shown in Figure 8. Only increasing individual competence is not enough to cope with the complexity increase. Later programs, therefore, shifted the focus to teams and influencing the team's context. The tracks take addressing the organizational complexity further by engaging a much broader target group. In this way, education strives to reach a tipping point [21] in the organization. An organization reaches such a tipping point when the education makes a visible business impact. This study does not provide direct evidence for such a business impact; the ongoing interest in education is an indication that the companies see its value. Figure 6 shows the relative increase in programs at the cost of courses and the growth of tracks in the most recent 3 years.

Figure 7 shows the growth of OEM participation at the cost of all other types of participants. From 2021, we see some suppliers returning. A major difference is that in the early years, participants were individuals, while the suppliers now are in joint OEM–supplier teams. The program becomes a means to lower boundaries between organizations in the ecosystem. Working with cross-boundary teams is not obvious; it requires trust. The cultural background of the region, the Rijnland model or social market economy, and the non-competitiveness of the kind of products help bring participants together across borders.

In these 20 years, we have observed a continuous scarcity of competent systems engineers. Competent systems engineers tend to be more than fully loaded in their organizations. Consequently, few systems engineers take the step to help develop other systems engineers; there is a scarcity of teachers.

ESI education evolved from domain and depth to system and leadership, from individuals to teams and organizations, from systems engineers to systems engineers and their direct coworkers, and from OEMs to OEMs and their partners in the ecosystem.

6.4. What Portfolio of Educational Offerings Fits an Industrial High-Tech Ecosystem?

The complex growth in all dimensions created an educational dilemma. On the one hand, we see that organizations in the ecosystem and the individuals working in them require significant competencies, as shown in Figure 9. On the other hand, organizational pressure reduces the absorptive capacity [21] and increases the cognitive load of individuals. We argue that individuals and organizations need educational offerings with sufficient room for customization. In design terms, we need educational building blocks that are loosely coupled to allow this customization. For depth and domain knowledge, courses are good building blocks that individuals may choose in a menu fashion. For integrative competencies, like system mindset, leadership, business, and innovation, programs with a longer duration and case-based active learning are more suitable. Lastly, tracks are the instrument to engage a critical mass of stakeholders in an ecosystem.

The region recognizes the need for education and at the same time, the scarcity of systems engineering teachers. In 2023, the government, companies, and education providers together started a program as part of NxtGen HIGHTECH (https://nxtgenhightech.nl (accessed on 11 September 2023)) to elicit education needs and develop cohesive educational offerings across the ecosystem. The purpose of cohesive education is to facilitate interoperability in the ecosystem. The education should cover all levels, e.g., bachelor, master, PhD, and lifelong learning. Hence, university colleges, universities, and other education providers are all stakeholders. Again, the trust between various partners, coming from the Rijnland model, is essential for the NxtGen program.

6.5. Conclusions and Future Research

Complexity is increasing socially as well as technically. At the same time, the ecosystem suffers from a shortage of systems competence. In developing system competencies, systems engineers and systems engineering teachers play a crucial role. Education has to focus on leadership, interpersonal skills, and an SE mindset while paying sufficient attention to business and innovation and providing some SE discipline knowledge. More education is available for less experienced employees in SE discipline, domain, and depth of knowledge and skills. Increasing complexity requires that the growing ecosystem as a whole has sufficient competence. OEMs require that suppliers and providers grow their competence; they should interoperate well with the OEM organization. ESI education evolved from a domain and depth to system and leadership, from individuals to teams and organizations, from systems engineers to systems engineers and their direct coworkers, and from OEMs to OEMs and their partners in the ecosystem. Combining informal learning and education is essential for developing systems engineering competencies.

Future education needs educational building blocks that are loosely coupled to allow for customization. Courses in a menu fashion serve individual needs for depth and domain knowledge. Programs, of several multi-day blocks, using case-based learning, serve the development of the system mindset, leadership, business, and innovation. Tracks are the instruments to engage a critical mass of stakeholders in an ecosystem. University colleges, universities, and other education providers have to cooperate in delivering cohesive education to all levels, e.g., bachelor, master, PhD, and lifelong learning. The challenge is to overcome individual interests and achieve education in the Netherlands that facilitates interoperability between companies further.

More research should evaluate the effectiveness of past education through a longitudinal study involving past participants and their employers. In addition, more research has to elicit the needs of suppliers and providers when broadening the scope of education. Future research has to validate and verify the education needs and the cohesive educational offerings across the ecosystem that still have to be developed.

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References

1. Dahmann, J.; Khaw, A.; Biloiu, I.; Jacobs, R.; Kim, C.; Thompson, C. Digital Engineering of Large Scale System of Systems: End-to-End (E2E) Modeling and Analysis Environment. In Proceedings of the 2021 16th International Conference of System of Systems Engineering (SoSE), Västerås, Sweden, 14–18 June 2021.
2. Törngren, M.S.U. Complexity challenges in development of cyber-physical systems. In *Principles of Modeling*; Springer: Cham, Switzerland, 2018; pp. 478–503.
3. Polojärvi, D.; Palmer, E.; Dunford, C. A systematic literature review of sociotechnical systems in systems engineering. *Syst. Eng.* **2023**, *26*, 482–504. [CrossRef]
4. Van Kappen, P.; van Bree, T.; Stolwijk, C.; Yagafarova, A.; van der Horst, T. *High-Tech Industry in 2040. New Challenges for Achieving Long-Term Earning Power and Impact for The Netherlands*; TNO: The Hague, The Netherlands, 2023.
5. Hoang, B. Turnover or Connection? The Influence of Employability Competencies Development Programs of Engineering Professionals on their Relationship with their Company. Master's Thesis, Utrecht University, Utrecht, The Netherlands, 2021.
6. Poort, C.G. Transfer of Soft Skills by Engineering Professionals from a Change Readiness Perspective (AVT). Master's Thesis, Utrecht University, Utrecht, The Netherlands, 2021.
7. Meier, B.; Skelin, M.; Beenker, F. HTSM Systems Engineering Roadmap. *Tech. Rep.* **2020**. Available online: https://hollandhightech.nl/_asset/_public/Innovatie/Technologieen/z_pdf_roadmaps/Roadmap-Systems-Engineering-update-2020-final-v20200724.pdf (accessed on 8 October 2023).
8. Shenhar, A.J.; Dvir, D. *Reinventing Project Management: The Diamond Approach to Successful Growth and Innovation*; Harvard Business School Press: Boston, MA, USA, 2007.
9. Muller, G. Experiences of Teaching Systems Architecting. In Proceedings of the INCOSE 2004, Toulouse, France, 20–24 June 2004.
10. Muller, G. *Systems Architecting: A Business Perspective*; CRC Press: Boca Raton, FL, USA, 2011.
11. Muller, G.; van den Aker, J.; Postema, H. Blended education for systems architecting Evaluation of the initial blended course version. In Proceedings of the 11th System of Systems Engineering Conference, SoSE 2016, Kongsberg, Norway, 12–16 June 2016.
12. Power, R. Maximizing the Impact of Instructional Video Length. In *Integration of Instructional Design and Technology*; Power Learning Solutions: Sydney, NS, Canada, 2022; Volume 2.

13. Guo, P. Optimal Video Length for Student Engagement. 2013. Available online: https://blog.edx.org/optimal-video-length-student-engagement (accessed on 10 July 2023).
14. IMF. GDP Per Capita, Current Prices. 2023. Available online: https://www.imf.org/external/datamapper/NGDPDPC@WEO/OEMDC/ADVEC/WEOWORLD/NLD (accessed on 3 July 2023).
15. Bakker, P.F.A.; Evers, S.; Hovens, N.; Snelder, H.; Weggeman, M.C.D.P. Het Rijnlands model. *Scope Period. Voor Tech. Bedrijfskd.* **2005**, *12*, 17–19.
16. Goldschmidt, N. *The Philosophy of Social Market Economy: Michel Foucault's Analysis of Ordoliberalism*; Freiburger Diskussionspapiere zur Ordnungsökonomik, Universität Freiburg: Freiburg, Germany, 2007; Volume 7.
17. Bakker, B.; Evers, S.; Hovens, N.; Snelder, H.; Weggeman, M. Het Rijnlands Model als Inspiratiebron. *Holl. Manag. Rev.* **2005**, *103*, 72–81.
18. Muller, M. Rijnlands Model. 2021. Available online: https://www.mejudice.nl/artikelen/detail/de-teloorgang-van-het-rijnlands-model (accessed on 8 October 2023).
19. Van Bavel, B. Open societies before market economies: Historical analysis. *Socio-Econ. Rev.* **2019**, *18*, 795–815. [CrossRef]
20. Greiner, L. Evolution and Revolution as Organizations Grow. *Harv. Bus. Rev.* **1972**, *50*, 37–46.
21. Phelps, R.; Adams, R.; Bessant, J. Life cycles of growing organizations: A review with implications for knowledge and learning. *Int. J. Manag. Rev.* **2007**, *9*, 1–30. [CrossRef]
22. Cohen, W.M.; Levinthal, D.A. Absorptive capacity: A new perspective on learning and innovation. *Adm. Sci. Q.* **1990**, *35*, 128–152. [CrossRef]
23. Kurtz, C.F.; Snowden, D.J. The new dynamics of strategy: Sense-making in a complex and complicated world. *IBM Syst. J.* **2003**, *42*, 462–483. [CrossRef]
24. Hoda, R.; Salleh, N.; Grundy, J. The Rise and Evolution of Agile Software Development. *IEEE Softw.* **2018**, *35*, 58–63. [CrossRef]
25. INCOSE. Systems Engineering. Available online: https://www.incose.org/about-systems-engineering/system-and-se-definition/systems-engineering-definition (accessed on 13 August 2023).
26. Pyster, A.; Adcock, R.; Ardis, M.; Cloutier, R.; Henry, D.; Laird, L.; Lawson, H.B.; Pennotti, M.; Sullivan, K.; Wade, J. Exploring the Relationship between Systems Engineering and Software Engineering. *Procedia Comput. Sci.* **2015**, *44*, 708–717. [CrossRef]
27. Prahalad, G.; Hamel, G. The core competence of the corporation. *Harv. Bus. Rev.* **1990**, *68*, 79–91.
28. Eraut, M. Informal Learning in the Workplace. *Stud. Contin. Educ.* **2004**, *26*, 247–273. [CrossRef]
29. Vermeren, P. *A Skeptic's HR Dictionary*; A4SK Consulting: Londerzeel, Belgium, 2019.
30. Jacobs, R.; Washington, C. Employee development and organizational performance: A review of literature and directions for future research. *Hum. Resour. Dev. Int.* **2003**, *6*, 343–354. [CrossRef]
31. Malan, R. Software Architecting; How is Software Architecture Created? Available online: https://bredemeyer.com/howto.htm (accessed on 13 August 2023).
32. Pyster, A.; Hutchison, N.; Henry, D. *The Paradoxical Mindset of Systems Engineers: Uncommon Minds, Skills, and Careers*; Wiley: Hoboken, NJ, USA, 2018.
33. Arnold, R.D.; Wade, J.P. A Definition of Systems Thinking: A Systems Approach. *Procedia Comput. Sci.* **2015**, *44*, 669–678. [CrossRef]
34. Hutchison, N.; Verma, D.; Burke, P.; Clifford, M.; Giffin, R.; Luna, S.; Partacz, M. *Atlas 1.1 Implementation Guide: Moving from Theory into Practice*; Systems: Hoboken, NJ, USA, 2018.
35. Hutchison, N.; Burke, P. *Helix Goes International: Observations on Systems*; TNO-ESI symposium in Eindhoven: Eindhoven, The Netherlands, 2019.
36. Razbani, O.; Muller, G.; Kokkula, S.; Falk, K. Enhancing Competency and Industry Integration: A Case Study of Collaborative Systems Engineering Education for Future Success. *Systems* **2023**, *11*, 463. [CrossRef]
37. Eraut, M. Assessment of Significant Learning Outcomes: 3rd Seminar Feedback and Formative Assessment in the Workplace. 2015. Available online: https://www.researchgate.net/publication/237739544_ASSESSMENT_OF_SIGNIFICANT_LEARNING_OUTCOMES_3RD_SEMINAR_Feedback_and_Formative_Assessment_in_the_Workplace1\T1\textgreater{} (accessed on 8 October 2023).
38. Sweller, J.; van Merriënboer, J.J.G.; Paas, F. Cognitive Architecture and Instructional Design: 20 Years Later. *Educ. Psychol. Rev.* **2019**, *31*, 261–292. [CrossRef]
39. Times, N.Y. The Tech Cold War's 'Most Complicated Machine' That's Out of China's Reach. 2021. The Tech Cold War's 'Most Complicated Machine' That's out of China's Reach—The New York Times. Available online: https://www.nytimes.com/2021/07/04/technology/tech-cold-war-chips.html (accessed on 3 July 2023).
40. Conway, M. How do committees invent? *Datamation* **1968**, *14*, 28–31.